NYSERDA

CENTRALLY MANAGED ROOM AIR CONDITIONERS FOR LOAD CONTROL AND DEMAND RESPONSE

Final Report

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NOTICE

Abstract

Distributed cooling in multifamily buildings has a compressor coincidence that drives peak electrical demand and that can be managed with communicating appliances and building controls. Two thirds of the room air conditioners in a New York City high rise master metered apartment building were replaced with new units that are wirelessly networked to an automated monitoring and control system. The system provides near-real-time information on air conditioner operation and apartment temperature conditions and can modulate an individual unit's setpoint and deactivate its compressor. A control algorithm was developed and tested with the goal of minimizing the monthly building peak electrical demand in the summer cooling months and to facilitate participation in a demand response program.

Billing peak kW demand reduction as a result of the control algorithm was analyzed using daily peak demand data. Based on an analysis of six hot days during the summer of 2012, the RAC control system reduced the daily peak demand by 4-6% (or approximately 6-9%, if all RACs in Jefferson Towers had been a part of the control system). The sacrifice made by residents to achieve this result was to experience a slightly higher cooling setpoint (75°F) for brief periods of time during the building's evening peak demand period. Very few (less than five) complaints related to the RAC control system was recorded during the summer of 2012, when the control system operated on about 50% of the summer days. The building successfully participated in seven demand response events over two summers utilizing the air conditioner control system and other load reduction measures, shedding 50-60 kW per four-hour event.

The energy benefits of this project included increased efficiency of new air conditioners, lower utility peak demand costs due to more efficient air conditioners, lower utility peak demand costs due to smart building control of the new air conditioners and demand response payments from curtailment of the air conditioners. Smart control of the RACs appears to have reduced the kW demand by 10 kW to 18 kW or about 4-6%. As a result of the project, cooling energy consumption declined by about 26% – yielding a projected $6,500 in annual savings.

Key words: peak load demand reduction; fleet-controlled air conditioning; demand response; cooling load control; multi-family; room air conditioners

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SUMMARY

The objective of this project was to demonstrate and evaluate the benefits of room air conditioner (RAC) load control in New York master metered multi-family buildings. The primary research questions were how master-metered multi-family building peak demand reduction (kW) can be achieved through dynamic control of individual RACs without significantly sacrificing resident comfort, how much kW reduction can be achieved, and what the value proposition of such a RAC control system is for New York City multifamily buildings (from master-meter bill savings and from leveraging the system to participate in a demand response programs during grid peaks).

A group of centrally controllable RACs was installed and tested in Jefferson Towers, a master–metered, 190-apartment building in New York City. In a master-metered apartment building all residential areas are served by a single utility meter. Individual apartments may or may not be submetered (apartments are submetered at Jefferson Towers). Two-thirds of the resident's roughly 350 RACs were replaced with units that are more efficient and can be remotely controllable using wireless communication. A central computer connected to the wireless network was programmed to selectively curtail the compressors of the RACs during times of high demand and thereby reduce the total building electrical demand.

Researchers operated the system over the summers of 2011 and 2012 with the following goals: refining and optimizing the control system; quantifying kW demand reductions; understanding impacts on occupant comfort; quantifying the cost and benefits associated with the system; and demonstrating demand response capability.

Each air conditioner is equipped with an internal wireless communication module that communicates with a proprietary building area mesh network (BAN) provided by the submeters present in each apartment. . These communicating RACs transmit operating status, thermostat setpoint and other information from each unit to a central computer located in the building. The central computer runs a program that analyzes total electric demand of the building and, using an algorithm developed for this project, minimizes demand by adjusting thermostat setpoints in selected air conditioners thereby turning compressors off in select units.

The building also enrolled in an electric demand response program of the New York Independent System Operator (NYISO). The system has the capability to deactivate compressors on participating RACs when a curtailment even is scheduled. Residents who received new air conditioners in this project had the option of participating in the demand response curtailments in exchange for a share of the revenue the building earned from the NYISO program. The control system successfully demonstrated the ability to curtail cooling equipment operation and drive down building demand during seven demand response (curtailment) events called by the NYISO. During some of the first 2011 events, outdoor temperatures were significantly higher than that envisioned by the NYISO baseline calculation method resulting in demand exceeding the

target demand for a portion of some of the curtailment periods, however this did not result in a failure to meet the building's curtailment obligation. It is concluded that, despite the successful performance of the RAC control system during demand response events, demand response programs are marginally suitable for mid-size multi-family buildings because of the baseline calculation methods; because the electrical peak of residential properties is in the evening, out of synch with the afternoon grid peak; and because of more stringent program requirements instituted in recent years.

Utility cost avoidance due to kWh consumption reduction was calculated as approximately $6,500 annually; utility cost avoidance due to kW demand reduction was calculated as approximately $2,200 annually. The consumption savings calculation used 2008 as the baseline year and was normalized for weather (cooling degree days) and adjusted for the additional cooling units added to the building. It factors in the savings due to the increased efficiency of the new RAC units and the kWh savings that resulted from the deactivation of RAC compressors during peak periods by the control system. The demand savings is based on an analysis of RAC operational data gathered from the control system in 2012: the cumulative time that the RACs were overridden by the control system during the building peak period for the month was tabulated; plus the demand savings as a result of the increased RAC efficiency.

To the authors' knowledge, this is the first time peak demand reduction has been quantified as a result of the operation of an RAC control system in a multifamily building. If all RACs had been connected to the control system at Jefferson Towers, it would have resulted in a 6-9% peak demand reduction with an occasional modest sacrifice in comfort demanded from participants in this demonstration. Residents were required to experience 75°F cooling setpoints for brief periods (a few hours) during the building's evening peak for a limited number of days each summer month. Further raising setpoints (perhaps up to 78°F) may be possible without resident resistance if duration is kept to a minimum. This could result in significantly greater demand reduction and bill savings

The system demonstrated in this project is the third generation of technologies employed in the pursuit of fleet load control of electric space conditioning equipment in New York City multifamily buildings. One unique feature of this project was the integration of electrical submetering with space conditioning control. The existing electrical submetering system included a wireless building area network (BAN) that the RACs use to communicate with the central computer. This BAN is also used to support heating control by feeding space temperatures (from a sensor internal to the submeter) to heating system valves.

Load reductions was achieved by controlling the air conditioners in such a manner as to be invisible to the residents, largely eliminate complaints, prevent tampering with the system, and achieve the desired demand management and demand response capability. This demonstration follows a small number of demonstrations done using earlier technologies in the New York multifamily building market segment over the past 30 years.

Section 1
INTRODUCTION

OVERVIEW

RAC use in New York City multifamily buildings is wide spread and, if managed through smart-building systems, can represent both a saving opportunity for the building and a significant resource for peak load reductions and demand response. The objective of this project was to demonstrate and evaluate RAC aggregation and load control in New York master-metered multi-family buildings. Master-metered buildings are common throughout New York State.[1] Because the electricity for all residential areas passes through a single utility meter, a master-metered building in New York City enjoys the benefits of a lower bulk rate for electricity, however it also pays a peak demand charge that can amount to one third of its electric costs.

The primary research question of this project was whether RAC operation can be managed automatically to reduce total peak building electric demand in a master-metered multi-family building while maintaining occupant comfort. Researchers also explored the financial benefits that can be leveraged from this technology, through participation in a demand response program.

In order to manage a building's peak demand, a smart-building system must have the following; 1) control of loads that contribute to peak, such as RACs, 2) control intelligence to optimize comfort while minimizing electricity demand and 3) a means of building area communication or networking to be aware of the factors being controlled, the level of comfort in the occupied space, and electrical demand.

This project addressed the research questions above by installing and testing a group of controllable RACs in a multifamily building in New York City. The demonstration site, Jefferson Towers, had an existing electrical submetering system that served as the building area networking platform for the smart-building system. The submetering system includes in-residence electrical meters, a shadow master meter and a central internet-connected computer, all communicating over a proprietary wireless communications network. The project replaced two-thirds of the building's approximately 350 RACs with commercially available units that were new and therefore generally more efficient than the units they were replacing. These RCA's were modified to be controllable, and communicating. These RACs were integrated into the submetering system's wireless network and the central computer was programmed with an algorithm

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[1] 105,000 buildings constructed under the Mitchell-Lama program (New York State Department of Housing and Community Renewal, 2013); approximately 180,000 master metered buildings under management of the New York City Housing Authority (New York City Housing Authority, 2012); plus additional Section 213 buildings and others.

developed to automatically manage curtailment of the RACs while maintaining a minimum level of comfort in order to reduce the total building electrical demand.

Researchers operated the smart-building system over the summers of 2011 and 2012 with the goals of 1) refining and optimizing the control system; 2) quantifying the kW demand reductions achieved; 3) understanding impacts on occupant comfort; 4) quantifying the cost and benefits associated with the system; 5) demonstrating a demand response capability; and 6) illustrating a method that similar buildings (master metered cooperative or condominium buildings) could use to implement like systems.

BACKGROUND

This report describes and evaluates the third generation of technologies employed in the pursuit of fleet load control of electric space conditioning equipment in New York City multifamily buildings. The first generation was installed at Manhattan Plaza. From 1979 to 1982 one of the authors of this report conducted a study at Manhattan Plaza[2] that demonstrated the use of an energy management system (EMS) to control over 3,000 thru-the-wall heating/air conditioning units via one-way power line carrier (PLC) communications to receivers installed in each heating/cooling unit which facilitated the separate control of the re-circulating fan and the refrigerant compressor. This one-way communication EMS system did not provide for command receipt verification but successfully demonstrated both an energy reduction and a demand response capability (Hirschfeld, 1980).

The second generation was installed at Waterside Plaza. In 1997 this same researcher successfully demonstrated a combination EMS/submetering system to control over 3,000 thru-the-wall heat pump units at the Waterside Plaza[3] complex. This dual system provided two-way PLC communications to apartments that enabled the issuing of control commands via the apartment heat pump branch circuits to control the heat pumps, as well as the ability to retrieve apartment submetering data for meter reading and billing. Because the control system was installed at the apartment circuit breaker, it did not permit the separate control of the space conditioning unit re-circulating fan and refrigerant compressor[4]

Both the Manhattan Plaza and the Waterside Plaza systems have been in continuous operation since their initial installation with the only modifications consisting of replacing the electrical-mechanical receivers at

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[2] Manhattan Plaza is a 1,690 unit all-electric residential complex located on the lower west side of Manhattan.

[3] Waterside Plaza is a 1,460 unit all-electric residential complex located on the lower east side of Manhattan.

[4] Applied Energy Group; Hirschfeld, Herbert P.E, 2002

Manhattan Plaza with solid state receivers and with replacing the through-the-wall combination heating/cooling units at both Manhattan Plaza and Waterside Plaza with air cooled heat pumps.

The system installed at Jefferson Towers represents the third generation of these systems. It utilizes two-way wireless radio communications inherent in the existing electrical submetering system to communicate with a controller that is an integral component of each of the air conditioning units.[5] It therefore combines the advanced technology features incorporated in both previous installations and enables superior control and feedback on apartment conditions. Significant technology advances in this generation include the ability to control the RAC units with a device internal to the RAC chassis, thereby permitting separate control of the compressor and the recirculating fan. This feature includes a built-in time delay that addresses the warranty requirements imposed by RAC manufacturers to avoid compressor short cycling. The tamper-proof internal controller also prevents residents from interfering with the project objectives and permits fan operation after disengaging the compressor, which better maintains the comfort level in the apartment and has the psychological benefit of masking the compressor cycles.

SITE DESCRIPTION

Jefferson Towers is a 190-apartment,[6] 20-story cooperative apartment building constructed in 1968 on the Upper West Side of Manhattan, as seen in Figure 1-1. Each apartment has two original through-the-wall air conditioner sleeves (one in the living/dining area with a dedicated 220-volt outlet and one in the master bedroom with a 110 volt outlet). Including sleeves in building common areas, there are approximately 400 through-the-wall air conditioner sleeves in the building, not all of which contain air conditioners.

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[5] These controllers were installed in standard RAC units to become integral to their operation.

[6] 38 one-bedroom units, 114 two-bedroom units, 38 three-bedroom units

Figure 1-1 Jefferson Towers, etc.

Jefferson Towers was constructed as a master-metered building. One utility electric meter serves all apartments and common areas. Apartments are submetered via wireless communicating submeters, installed in 2003. A central computer communicates with the submeters and transmits electrical usage data via the internet. A billing service provider collects the usage data, calculates billing amounts by apartment and transmits billing information (usage and charges) to the management company for inclusion in monthly statements to residents. Electrical costs to the building range from $200,000 to $250,000 annually with approximately two-thirds of that being used in apartments and the remainder in common areas.

The building's main meter is on Consolidated Edison electrical service RA 08 (utility tariff for customers with a third party commodity supplier). Power is supplied by a third party energy supplier. Approximately one-third of the electricity expenses are based on demand as determined by billing period peak loads, with most of the remaining charges for supply. Peak electrical demand in summer months is typically in the 320-380 kW range (see Table 1-1), with somewhat more than half of this attributable to cooling loads. In the year prior to submetering of electricity (2002) the peak load was 468 kW.

Table 1-1 Jefferson Towers historical peak demand levels in kW

Month	2012	2011	2010	2009	2008	2007
May	284	316	268	164	156	204
June	316	312	348	168	360	296
July	336	348	380	252	340	340
August	292	296	320	320	268	352
September	252	216	332	164	264	260

Other information about the building follows:

- Living/dining/kitchen areas are approximately 500 sf with 50-75 sf of glazing depending on apartment type. Most of the living/dining glazing is shaded by balcony overhangs. One RAC sleeve is located in this area.
- Master bedrooms are approximately 150 sf with approx. 40-50 sf of glazing without significant shading. One RAC sleeve is located in this area.
- Windows are low-e insulated glass with thermal breaks, installed in 2002.
- Common areas include hallways and trash rooms on 19 floors, two stairwells, a two-level below ground parking garage for approximately 100 cars, outer and inner lobbies, laundry room, community room and basement storage rooms.
- Commercial areas include seven retail and professional office spaces separately metered for electricity.
- Other areas include a management office, superintendent office and workshop and mechanical equipment rooms.
- Lighting is fluorescent throughout common areas. Occupancy sensors control lighting in a few locations such as the laundry room and tenant storage rooms..
- Space and water heating is currently provided by Consolidated Edison steam.
- RACs are present in the management office (occasional use), community room (occasional use), superintendent's shop and laundry room.
- A ducted cooling system was installed in the outer lobby in 2011.

As would be expected, resident behavior with respect to cooling varies. Some residents use air conditioning sparingly and only when they are home; others leave it on all day every day for the entire summer. This is mostly a matter of personal habit rather than where the apartment is within the building, although cooling load does vary by location. The dominant building facades face east and west. The western façade has no adjacent buildings over five stories high so apartments on the western side of the building receive direct sun for much of the afternoon. Despite many of the living/dining area windows being shaded by balconies, this side of the building tends to be warmest according to residents. Also anecdotally, residents report that the top floor gets very hot, presumably because of the sun on the roof (although the roof is insulated) and because windows on that floor do not have balconies shading them from above.

The electrical load shape for a typical summer weekday and weekend day is shown in Figure 1-2 and Figure 1-3 respectively. The building demand typically peaks between nine and ten pm on weekdays and between five and ten pm on weekends. Because many residents are at work during the week, demand tends to be moderate during the early part of the day, gradually picking up throughout the afternoon and coming to a pronounced, brief peak during the evening when most residents are at home and still awake. Cooling in both living rooms and bedrooms is active at this time; lights, entertainment equipment and dishwashers are likely to be on as well. On weekends, demand tends to spread out as schedules are more variable – people are home during the day and possibly out at night or away for the weekend in the summer. Peak demand tends to be slightly lower during weekends than weekdays for these reasons.

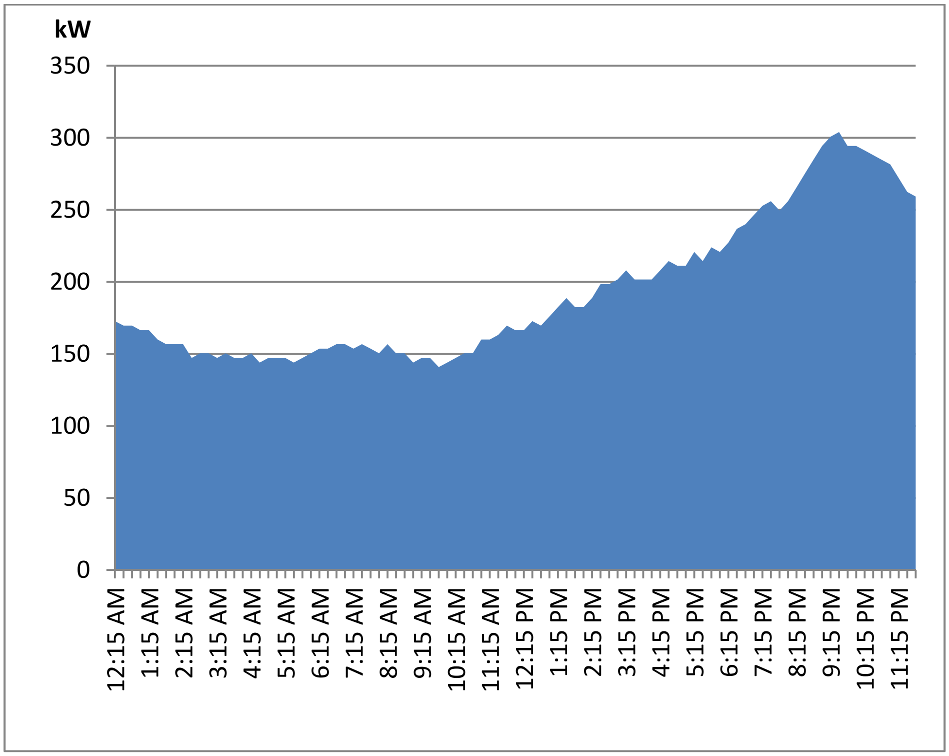

Figure 1-2 Building electrical demand on a typical summer weekday (8/6/07) - high temperature of 82.9 degrees F

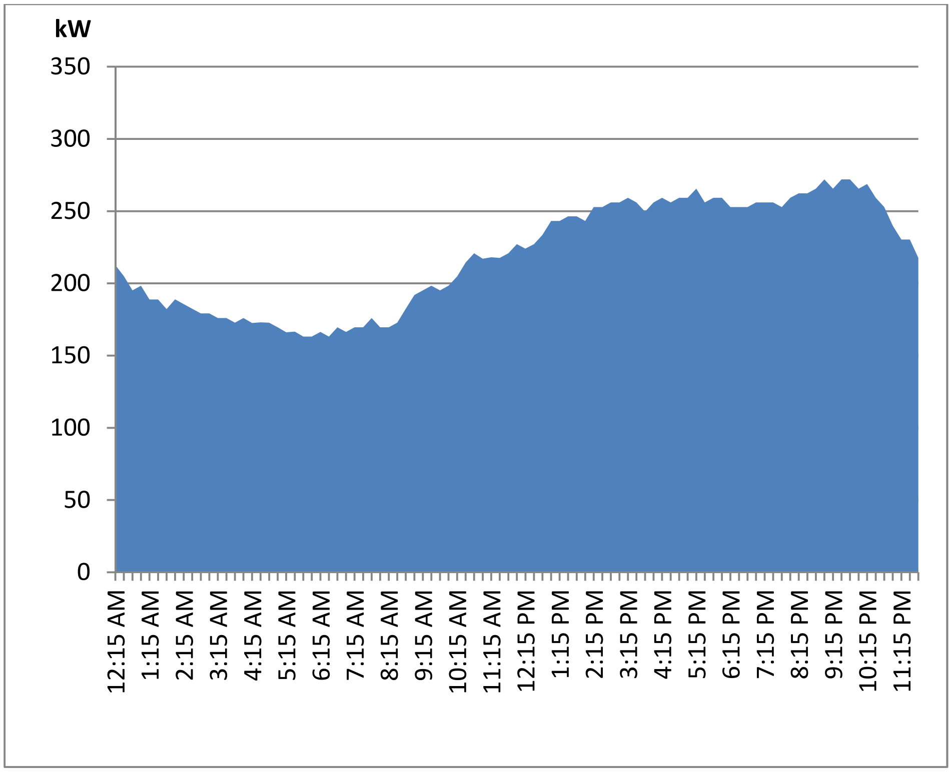

Figure 1-3 Building electrical demand on a typical summer weekend day (8/4/07) - high temperature of 89.1 degrees F

ROOM AIR CONDITIONERS

Prior to the retrofit the building had an estimated 300 room air conditioners installed. The retrofit added 230 new units. Ninety-eight were 9,000 Btu/hr bedroom units and 132 were 12,000 Btu/hr living room units. All new units had an energy efficiency ratio (EER) of 9.4. The 230 new units replaced 175 old units, resulting in an increase of 55 new RACs. The average EER of the removed units was 8.77. The average capacities of the removed units were 8,308 Btu/hr for bedroom units and 12,862 Btu/hr for living room units. The average per RAC capacity for the entire building (accounting for new and existing units, assuming the profile of the existing units was identical to the profile of the removed units) changed from 11,300 Btu/hr to 10,900 Btu/hr as a result of the retrofit.

Section 2

CONTROL SYSTEM

This section of the report describes the RAC control system deployed at Jefferson Towers. The system components include 1) the RACs with integral wireless controller, 2) the building area network built on existing apartment electric submeters, and 3) the central internet-connected computer running the 4) RAC control software (Figure 2-1). The key components of the system are described in more detail below.

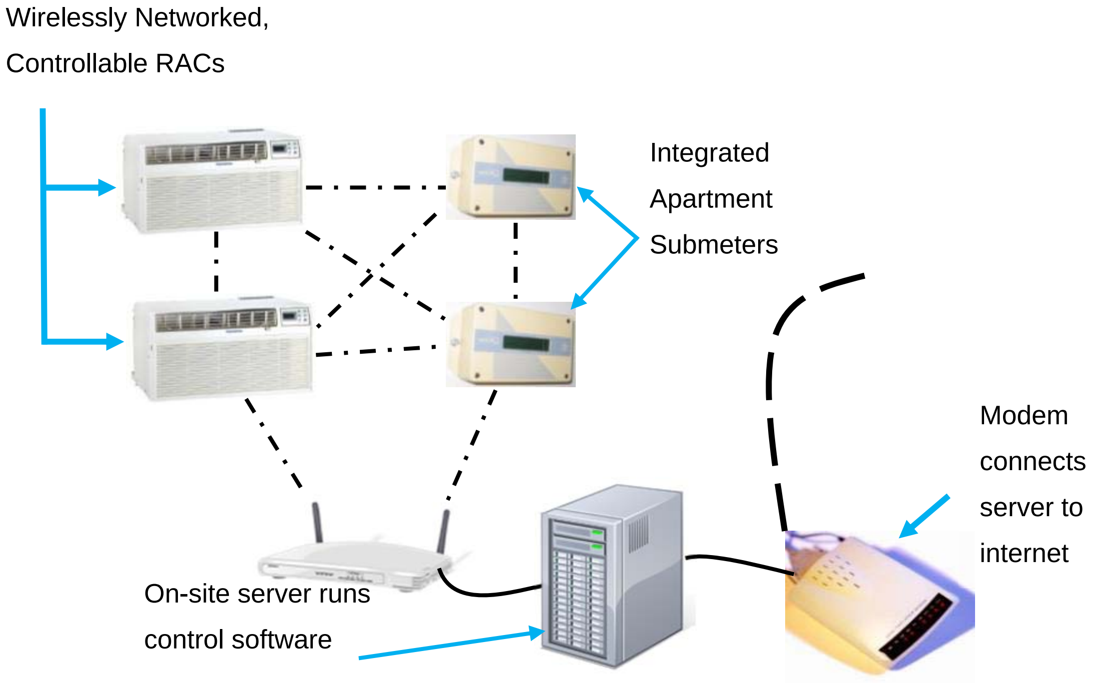

Figure 2-1 Schematic of fleet-controlled RAC system

CONTROLLABLE RAC

The RACs utilized at Jefferson Towers were off-the-shelf units built for through-the-wall sleeve installation. Technicians retrofit each RAC to add a new control board, radio transceiver and temperature sensor. The new control board has the ability to override the existing RAC controller provided with the unit. It has been found desirable to have the ability to control the RAC units with a device internal to the RAC chassis, thereby permitting separate control of the compressor and the recirculating fan in such a manner as to 1) provide air circulation and 2) not nullify the RAC manufacturer's warranty[7]. By installing a two-switch receiver inside the chassis – one switch controlling the thermostat and the second controlling the main unit on/off switch – the control strategy was able to ensure a three minute delay before the compressors were re-activated following a shutdown command. This allowed for sufficient time for pressure equalization to occur across the inlet and discharge of the compressor – thus maintaining the warranty requirement.

In addition to the controller, a radio communication device configured as a wireless network node is installed in the RAC cabinet. The radio has the ability to communicate operational information about the RAC over the network, including: return air temperature, thermostat mode, fan speed and compressor operation.

Each RAC has a unique ID number enabling them to be grouped by any predetermined characteristic – e.g. all bedroom units; or all units on the west side of the building. RACs can also be grouped by a variable – e.g. all RACs with a return air temperature above 80 degrees; all RACs with cooling enabled; or all units that have been deactivated for a specified period of time (utilizing time stamping).

BUILDING AREA NETWORK

The building area communications network existed as part of the electric submetering infrastructure. Each submeter (and now each controllable RAC as well) serves as a node in the self-healing wireless mesh network. In a mesh network, each radio node, in addition to capturing and disseminating its own data, also serves as a relay for other nodes, that is, it collaborates to propagate the data in the network[8]. The network also includes three receivers: one located at each end of the building on the ground floor and one centrally located on the twelfth floor. These receivers are hard wired to the central computer and serve to pick up the wireless signals and transmit them to the computer.

CENTRAL COMPUTER

The wireless controllers in the RAC units communicate with a local computer running customized RAC control software. This computer serves as the hub for the network of wirelessly communicating equipment, in this case electrical submeters and RACs, located in the building. It also includes the gateway to the internet where it accesses secure software residing in remote servers. The computer runs the control

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[7] (Applied Energy Group; Hirschfeld, Herbert P.E, 2002)

[8] (Wikimedia Foundation, Inc., 2012)

algorithm, stores system data, feeds that data over the internet to servers (which make it available on the web), issues commands to local equipment, and receives instructions (e.g. to change a control system setting) from the remote servers when initiated over an internet connection by an operator. Building management personnel have the ability to both monitor and modify certain control elements such as establishing setpoints and curtailment schedules via the internet.

CONTROL SOFTWARE

A detailed description of the control logic is in Section 3. The following paragraphs describe the basic mechanism that the control software is built upon.

Each RAC has two independent cooling setpoints: the local setpoint input by the resident at the unit keypad, and the control system setpoint established by the software running on the central computer. The compressor is responsive to whichever of the two setpoints is higher. When the control system issues a command to change the setpoint of a given RAC, that new setpoint is stored in the new retrofitted control board until it is altered by a subsequent command or until an expiration time of two hours has elapsed, after which the control system setpoint reverts to the minimum of 60°F. The two-hour limit prevents a communication breakdown from locking the RAC at an undesired control system setpoint.

RAC compressors, which represent approximately 90% of the total air conditioner load, can be disabled (turned off) by a command issued by the automated control software. This is accomplished by raising the setpoint of an RAC (or group of RACs) above the return air temperature (as measured by the return air sensor integral to the air conditioner), causing the thermostat to be satisfied and the compressor to turn off. When the compressor is deactivated the recirculating fan continues to operate, providing air movement in the apartment and avoiding the psychological disruption of hearing the unit go silent.

To return the RAC to resident control (resident's original setpoint), the control system setpoint is lowered a point below the resident's setpoint. This can be the minimum value (typically 60°F) or another value established as a "floor" cooling setpoint. Because the higher of the two setpoints (the control system setpoint and the resident setpoint) governs, the resident's setpoint will control when the control system setpoint is lower. The resident's setpoint remains unchanged on the unit's LCD display even as the control system setpoint is adjusted. An explanation of controllable parameters and status indicators is provided in Table 2-1.

The control system will not permit a compressor to turn on within three minutes of turning off in order to ensure pressure is equalized to prevent damage to the unit.

Table 2-1 Explanation of status and controllable parameters

Parameter	Value	Explanation
Status parameters – not directly controllable		
Temperature	Numeric	Return air temperature (RAT) measured at the air conditioner
Thermostat mode	Cooling / Heating	For heat pumps, heating mode is an option; for Jefferson Towers this will always be Cooling
Low, Med, High	ON / OFF	Indicates fan speed, if operating
Compressor	ON / OFF	Indicates if the compressor is running
Controllable parameters		
Cooler	Enabled/Disabled	Used to manually enable or disable the compressor without changing the setpoint (See “Thermostat” below)
Thermostat	ON / OFF	If “ON,” the thermostat controls compressor operation; if “OFF,” compressor operation can be controlled manually by Enabling/Disabling the “Cooler” field (see above)
Dead-band	Numeric	Sets the thermostat dead-band
Day Setpoint	Numeric	The thermostat setpoint for daytime
Night Setpoint	Numeric	The thermostat setpoint for nighttime
Time of Day	Day / Night	Displays the time of day. Can be changed.
Temperature Adj.	Numeric, -20 to +20	A temperature adjustment that can be applied to the “Temperature” value to compensate for the location of the unit (e.g. the air temperature may be higher or lower deeper into the apartment than at the periphery where the RAC is)

Section 3

CONTROL LOGIC

The control capability is used to reduce the building's kW demand for two purposes: 1) peak demand reduction each billing period (demand management); and 2) curtailment during demand response events (demand response). These two modes correspond to two subsets of air conditioners in the building as shown in Table 3-1, and are described below.

Table 3-1 Control modes and affected groups

Purpose (mode)	RAC group
Demand management	All networked RACs (as a precondition of purchasing the discounted RAC, residents consented to participate in the peak reduction program)
Demand response	Voluntary participants from among networked RACs (residents enrolled in this option in exchange for a share of the building's demand response payment)

DEMAND MANAGEMENT

Utility demand charges at Jefferson Towers are based on the two consecutive 15 minute time intervals with the highest demand during the billing period. The objective of demand management is to reduce building peak demand during each utility billing cycle.

A variety of approaches for achieving reduced building peak demand are theoretically possible:

1) Minimize demand by turning all controlled RACs off. Over time, temperatures in residences would reach unacceptable levels. Therefore compressors would then be activated, rationing the allowable demand up to but not exceeding the target.
2) Rationing kW demand (rationing compressor capacity) by giving permission for a certain number of compressors to be on at any one time or conversely deactivating a certain number of compressors as needed to reduce total building demand to acceptable levels.
3) Rationing comfort (temperature) by strategically increasing the control system setpoint as total building demand peaks in order to deactivate some compressors. The number of compressors affected by each increase in control

system setpoint could be predicted by examination of the return air temperatures.

4) Pre-cooling in anticipation of cooling demand based on a weather forecast. This would require anticipating the time of building peak. The control system, however, does not allow for compressor operation below the resident's setpoint, nor can RACs be activated when they are turned off by residents.
5) Cycling off and on groups of RACs periodically. This is the most familiar approach to cooling load control. It does not require knowledge of space temperatures unless cycling frequency or group composition is to be based on comfort.

With any of these strategies, once demand is reduced, the system must maintain the new lower demand. When the control period is over, the system must return all the air conditioners to resident control (resident setpoints) or some other lower setpoint without causing a spike in demand that exceeds the target. The method of releasing control must consider that resident setpoints may have changed (lowered) during the control period.

The demand rationing strategy (#2 above) was selected for implementation at Jefferson Towers because first shuts off cooling in rooms with the lowest air temperatures, and only later allows temperatures to increase in other rooms. By allowing the maximum demand to increase over the course of a day if necessary, a minimum comfort level can be maintained. This strategy calculates the demand in kW available to the controlled air conditioners given a predetermined total building target demand (Managed Demand). This kW demand available to the controlled RACs is calculated by subtracting the current uncontrolled load from the Managed Demand target. Figure 3-1 illustrates the relationship between total demand (Dt), uncontrolled cooling demand (Du) and controlled cooling demand (Dc).

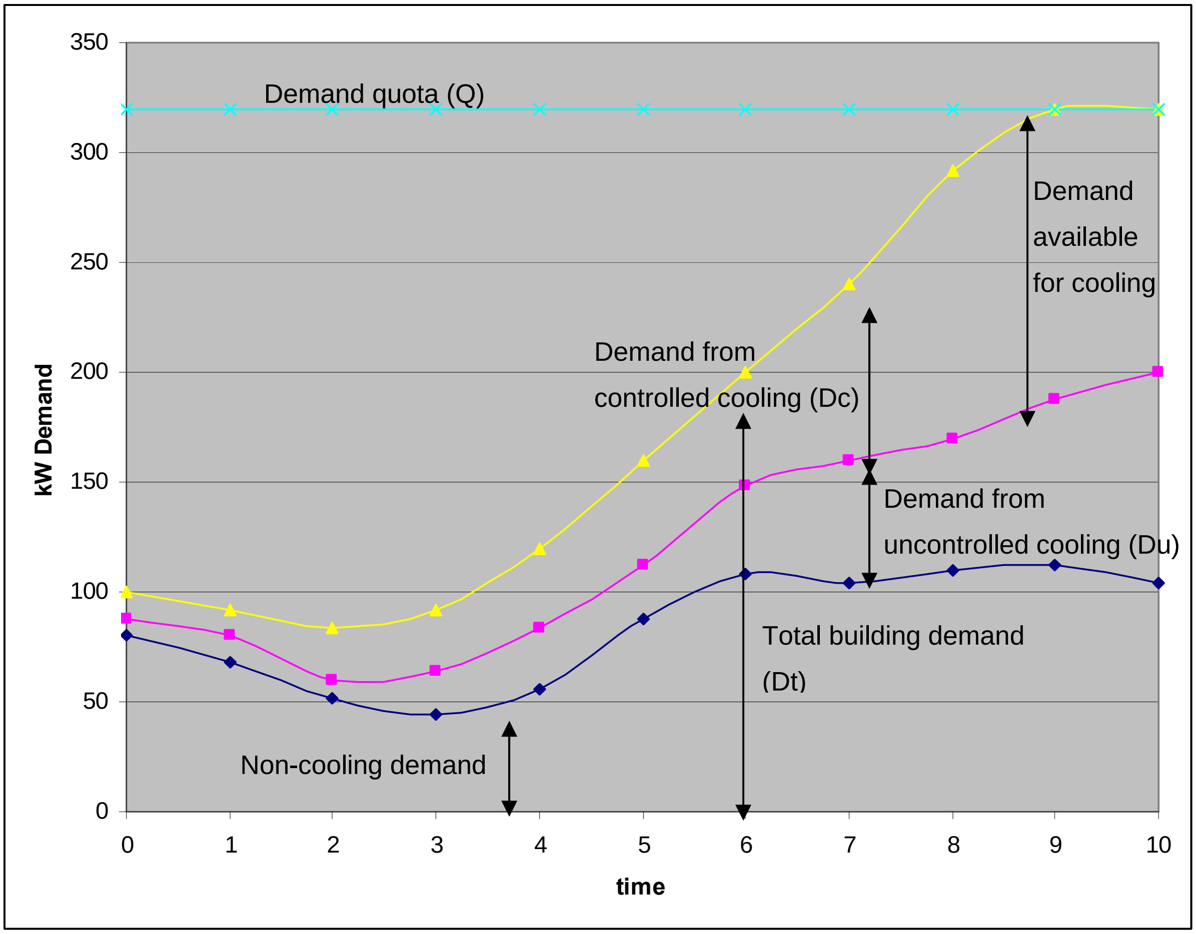

Figure 3-1 Sample building demand graph

The Managed Demand target is selected by examining historical bill data and then input by building management personnel. This serves as the starting point for the maximum kW demand target. The control algorithm runs continuously. It assembles a list of all controlled air conditioners (the “prioritization table”) that is used to determine which rooms have the least need of cooling, and consequently which compressors to deactivate. The RACs at the top of the list have the greatest demand for cooling, and thus are least likely to be deactivated. Within the prioritization table, the controlled RACs are sorted according to the following priorities: [9]

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[9] The return air temperature and other data are monitored and recorded as long as the air conditioner is plugged in to an outlet, regardless of whether it is turned on or off by the occupant.

1. RACs in cooling mode (i.e. the resident wants to engage cooling) are ranked above those not in cooling mode.
2. RACs for which the return air temperature (RAT) is equal to or greater than the maximum allowable RAT (RATm) are ranked above those for which the RAT is lower than RATm.
3. Living room units are ranked above bedroom units during daytime and vice versa.
4. Finally, RACs are sorted by RAT within these groups, with the highest RAT ranked highest.

Table 3-2 is a hypothetical example of a prioritization table. It lists all controllable RACs with the priority values displayed, ranked in order of priority with the first RACs on the list being the most in need of cooling and the least likely to be shut off. The lower an RAC is on the list the more likely it will be deactivated. The Compressor Status column indicates whether a unit is cooling (compressor on) or calling for cooling but overridden by a higher control system setpoint (status = 1) or whether the unit is off or its resident-controlled setpoint is satisfied (status = 2). The RAT ≥ RATm column reads yes if the return air temperature measured at the air conditioner is equal to or higher than the maximum allowable return air temperature established by the control system. Room is either living room (LR) or bedroom (BR). RAT is the current return air temperature. kW rating is the power drawn by the unit compressor (living room units have a higher kW rating than the bedroom units). SPc is the control system setpoint for that unit.

Table 3-2 Prioritization Table Example

AC ID#	Compressor status (ON or OFF/OVERRIDDEN (i.e. calling for cooling = 1; OFF = 2)	RAT ≥ RATm (YES / NO)	Room (L/B)	RAT	kW rating	SPc
1	1	YES	L	78	1.14	60
2	1	YES	L	78	1.14	60
3	1	YES	B	78	0.77	60
4	1	NO	L	73	1.14	60
5	1	NO	L	73	1.14	60
6	1	NO	L	72	1.14	60
7	2	NO	B	70	0.77	60
8	2	NO	B	68	0.77	60
9	2	YES	L	84	1.14	60
10	2	YES	B	82	0.77	100
11	2	YES	L	81	1.14	100
12	2	YES	L	79	1.14	100
13	2	YES	L	78	1.14	100
14	2	NO	B	69	0.77	100

Demand is allocated to all units in cooling mode where the RAT is equal to or greater than the maximum allowable RAT (RATm) – this is termed the "mandatory group." Then any remaining available demand is assigned to RACs down the list in priority order until the total kW quota is exhausted. Compressors of all remaining units are deactivated by maintaining a higher control system setpoint. If, after assigning demand to the mandatory group, the Managed Demand target is exceeded (i.e. the kW required by the Mandatory Group exceeds the allowable quota), then the peak demand at that time becomes the new Managed Demand target for the remainder of billing period (i.e. total demand is allowed to escalate to maintain comfort). All other RAC compressors are deactivated. The prioritization cycle begins again by calculating the available demand and re-sorting the list of RACs and is repeated every few minutes. A short waiting period is necessary to accommodate latency in the submetering communications system (data relays, system-wide response and registering the demand at the master meter).

The Managed Demand target (Dm) is initially established based on historical data (e.g. 20-30% below the average for the given month) and refined with experience. Selecting a low Managed Demand target is possible because it will automatically increase to keep all controlled RACs under the maximum RAT. A flow chart and detailed description of the control logic follows in Figure 3-2.

Variables used in Figure 3-2:

- Dm = Managed demand (building peak demand) target set in collaboration with building management
- Du = Total current building uncontrollable load due to non-controllable ACs, non-cooling uses and non-compressor load from controllable ACs
- Dt = Current total building demand
- Dc = Sum of kW ratings (compressor only) of all active (compressor on) controllable ACs
- Dt = Du + Dc
- Q = kW quota available to the controllable ACs
- Q = Dm – Du
- RAT = Return air temperature at the AC unit
- RATm = Maximum allowable RAT established by building management
- SPc = Control system setpoint
- Dr = Rated compressor demand of individual RAC
- Dmandatory = Sum of rated kW allotted to all RACs in the mandatory group
- Davailable = kW available for allotment to non-mandatory RACs

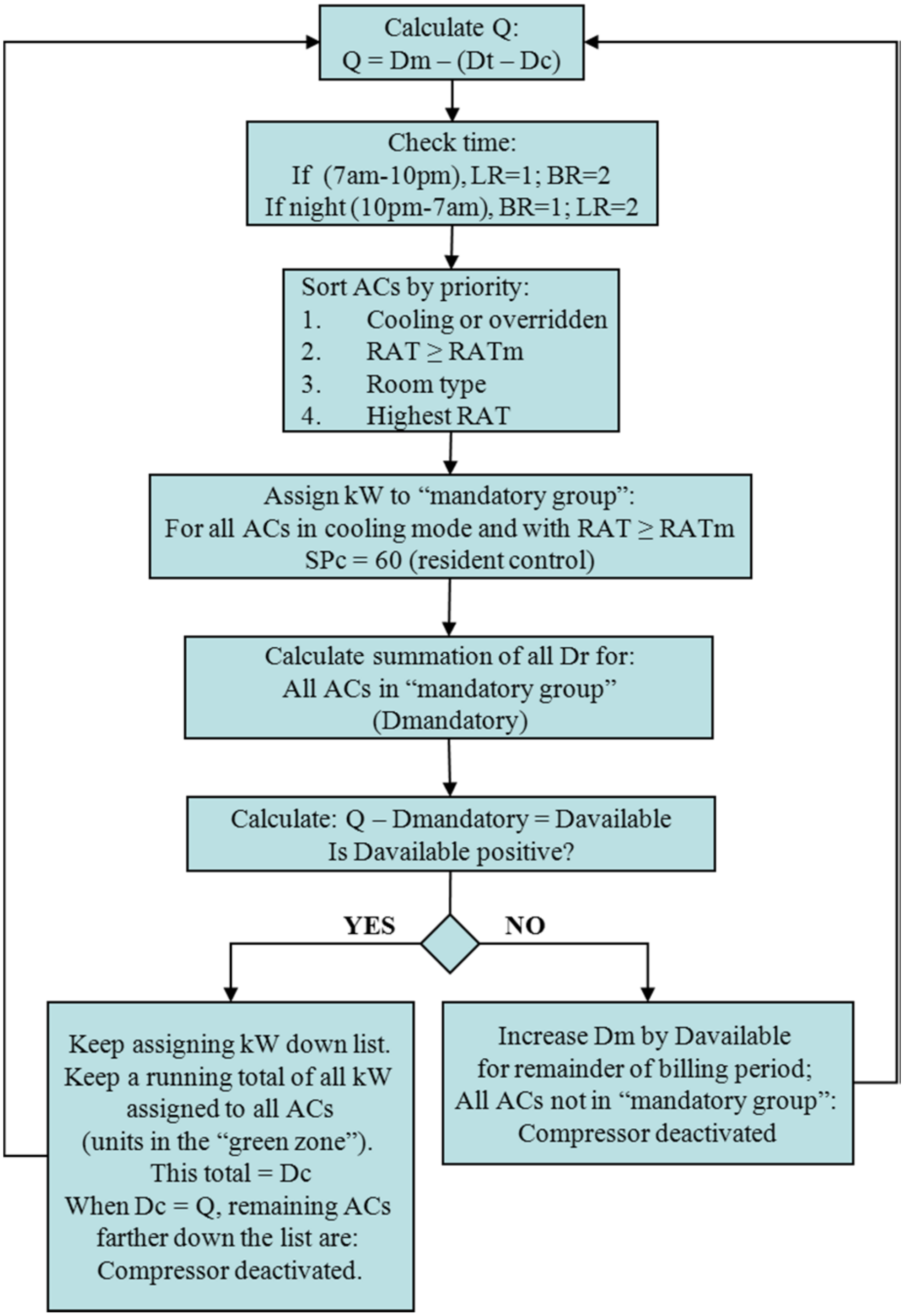

Figure 3-2 Control strategy flow chart

Control system operation

1. The control system continuously (every 5 min) sorts a table of all controllable air conditioners according to the previously discussed priorities.
2. All RACs start with a control system setpoint of 60 degrees F (resident enabled control) or other minimum value. Once the prioritization table is sorted, kWs are allocated as follows (starting at the top of the table):
   a. To all units where either the RAC's compressor is ON or its thermostat is calling for cooling (OFF/OVERRIDE) (priority group #1 above) AND where RAT is equal to or greater than RATm. This is the Mandatory group that is always allowed to run.
   b. If, after assigning kWs to the Mandatory group, Dc exceeds Q then Dm is reset to equal Du + Dc.
   c. If, after assigning kW to the Mandatory group, Q exceeds Dc, then the additional available kWs are assigned to RACs down the priority list (adding their kW ratings to Dc) in the priority order until Dc = Q.
   d. All remaining compressors are deactivated/remain deactivated by raising/retaining their control system setpoints (SPc) to a high setpoint.
   e. Upon the start of a new utility billing period, a new (reset) Dm target is established.

   Under this strategy controllable RACs remain under resident setpoint control until Dc exceeds Q (as a heat event worsens, Q will continually shrink due to increasing uncontrollable cooling load).

Example

Following is a hypothetical example (see Table 3-2)

1) If Q = 6kW, only the first six RACs' compressors would be allowed to run.
2) As the heat event progresses and the uncontrolled cooling load increases, Q shrinks to 5kW.
3) Unit #6, having the lowest RAT of the active units, would drop off the active list and its compressor would be shut off. It would remain off until:

   - Q increases; or
   - #6 moves up the priority list because its RAT increases above an active unit higher on the list or because an active unit higher on the list was shut off by a resident; or
   - Its RAT reached the maximum value permitted (RATm).

Notes

- If all controllable units (where the compressor is on or calling for cooling) reach RATm, then Dm is allowed to escalate to maintain all controlled RACs at RATm.
- A dead-band of perhaps 2 degrees would mean that these RACs would be allowed to run until their RATs were 2 degrees below RATm, then be shut down and allowed to float back up to RATm. The dead-band prevents units from cycling on and off too frequently, and prevents all units from turning on at the same time.[10]

DEMAND RESPONSE MODE

While the demand control mode runs continuously throughout the cooling season, the demand response mode kicks in only during curtailment events to completely deactivate the compressors of selected RACs for the duration of the event. The demand management mode continues to run on non-curtailed units throughout the demand response event. Selected units are designated for curtailment during demand response events based on voluntary resident enrollment. Shortly before the curtailment event begins a command is broadcast to raise the setpoints in all enrolled units to a level where the compressor will not turn on (e.g. 95°F). Curtailment events generally last four hours, after which the setpoint is reduced and the enrolled RACs are returned to the pool of units under demand management.

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[10] When a compressor is shut down it must be prevented from turning on for at least approximately five minutes to avoid compressor damage. One option to achieve this is by time stamping units when compressors are shut off.

Section 4

DEMAND MANAGEMENT

INTRODUCTION

The Managed Demand target for the buildings was set low enough – below what would be a typical summer day building peak – to ensure that the control system was frequently active and automatically managing RAC operation. As is demonstrated below, this resulted in active control of the smart RACs by the central control system on nearly every day the system was turned on. A range of temperature setpoints was tried without significant complaints from residents about being too hot, although the survey conducted at the end of the 2011 cooling season survey did reveal that some residents would have preferred more cooling on hot days. As a result, setpoints were made slightly lower in 2012. The setpoint applied to "activated" units was decreased from 72°F to 68°F and the setpoint applied to "deactivated" units was decreased from 77°F to 75°F.

UNIT LEVEL OPERATION

It is instructive to examine the impacts of the control system on the operation of a few typical RAC units. The following examples show two types of resident RAC operation behavior and demonstrate how the control system affected the operation of each. Figure 4-1 illustrates a typical RAC behavior, showing three parameters: return air temperature (dark blue), control system day setpoint (green) and compressor status (light blue). On this day (July 18, 2011) outdoor air temperature reached a high of 95°F between 2:00 and 3:00 pm. The graph begins at midnight with the RAC in the off position. It is turned on shortly after 8:00 am. The room temperature rapidly declines from about 80° to about 75°. The compressor remains on throughout the day with the room temperature slowly declining until it flattens out at 72° about 5:00 pm. The continuous operation of the compressor indicates that the unit probably never reached its locally established setpoint. Starting in the evening, when the building typically approaches its peak demand, there are two periods when the control system setpoint for this unit (green line) increases from 71° to 75° in order to deactivate the compressor in an effort to reduce building demand. During these periods the compressor is overridden a number of times and the room temperature increases to near the new 75° setpoint for periods of time. At about 10:30 pm the unit is shut off by the occupant and the temperature begins to increase.

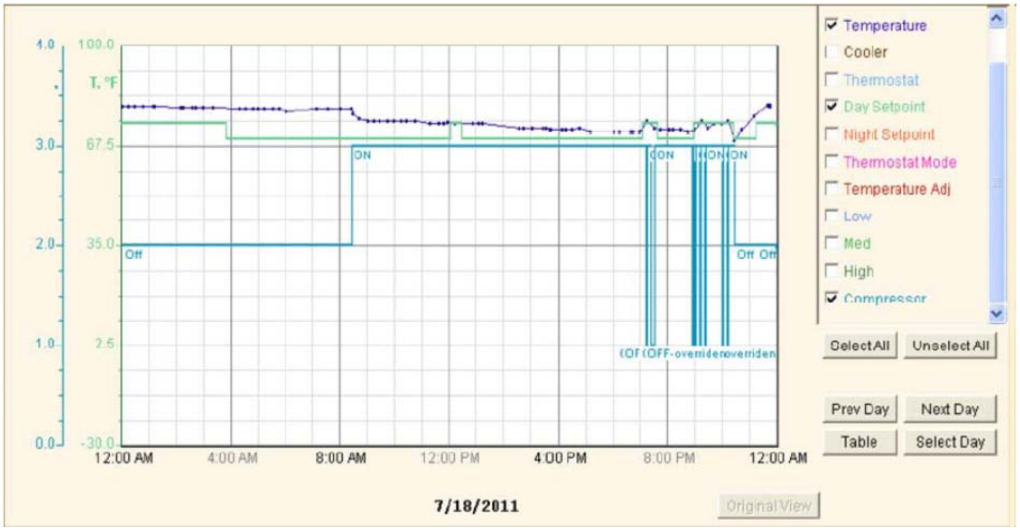

Figure 4-1 Example unit 1 operation

Figure 4-2 illustrates a unit that is operated somewhat differently by the occupant. On this day (July 17, 2011) outdoor air temperature reached a high of 90°F between 3:00 and 4:00 pm. The RAC was left on by the resident for the entire 24-hour period covered by this graph. In addition, it is entirely controlled by the control system setpoint, indicating that the occupant-established setpoint is lower than the control system setpoint. The room temperature hovers near the control system setpoint throughout the day including during four periods when the setpoint increases as part of the building demand control system operation. Note that the 12:00 pm setpoint increase is due to a daily test of the system, not a result of a need for peak demand reduction. Also note that the control system setpoint increased at about 5:30pm, well before the likely building peak. This is a result of a low Managed Demand setting that started actively controlling units well before necessary.

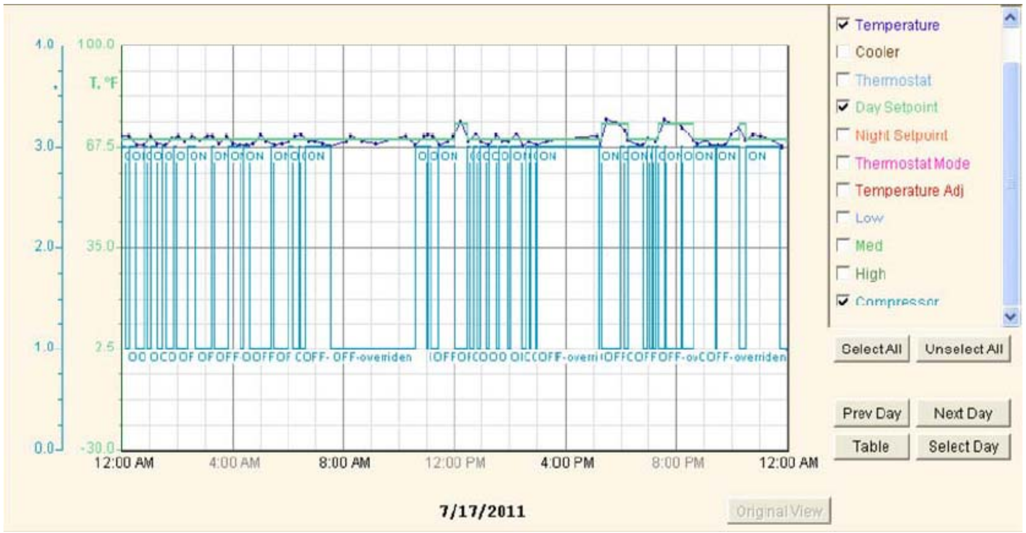

Figure 4-2 Example unit 2 operation

SUMMARY OF OVERALL SYSTEM OPERATION

This section reviews the overall system behavior by examining total building demand and key control system parameters over the course of a few typical summer weeks. Figure 4-3 and Figure 4-4 show the system response and weather data for the first nineteen days of July 2011. During this period, the control settings were as follows:

- Managed demand target (Dm) at onset of period: 194 kW
- Maximum return air temperature limit (RATm): 73°F (units above this return air temperature would be put into the mandatory group)
- Control system setpoint established for all units allowed to run (SP_on), which effectively is the minimum temperature allowed: 70°F
- Control system setpoint established for all units to be turned off (SP_off), which is effectively the maximum temperature allowed: 75°F (note that the SP_off limit serves as a failsafe temperature; if communication lagged or failed no unit should operate higher than this setpoint.)

The values shown on the graphs are defined below:

- C_on = Sum of compressor demand of controllable RACs at a given moment
- Dmdt = Sum of rated kW allotted to all RACs in “mandatory group”
- Dm = Managed demand target
- WkdayDt = Total building demand, weekdays
- WkdayDt = Total building demand, weekends
- Temp = Outdoor air temperature from local weather station
- Humidity = Outdoor humidity from local weather station

The following observations can be made from the data (letters are labeled on the graph):

A. Overall building peak (Dt) was generally higher on weekdays than on weekends and the July 4th holiday.
B. Dmdt roughly coincides with C_on during peak periods when Dt reaches Dm.
C. Dm steps up following spikes in Dt, however it lags slightly behind and below increases in Dt Daily peak demand generally rises with higher temperatures with a lag on the order of a few hours to half a day.
D. A small dip in Dt is evident on each day around noon due to a 20-minute scheduled system curtailment test run each day.

E. A dip in Dt is evident in the afternoon of July 19 due to the NYISO system wide one hour demand response test.

F. The building peak demand occurs between 9:00pm and 10:00pm on weeknights and falls off sharply to bottom out between 5:00am and 6:00am.

G. Dm lags slightly behind and below increases in Dt due to communication time.

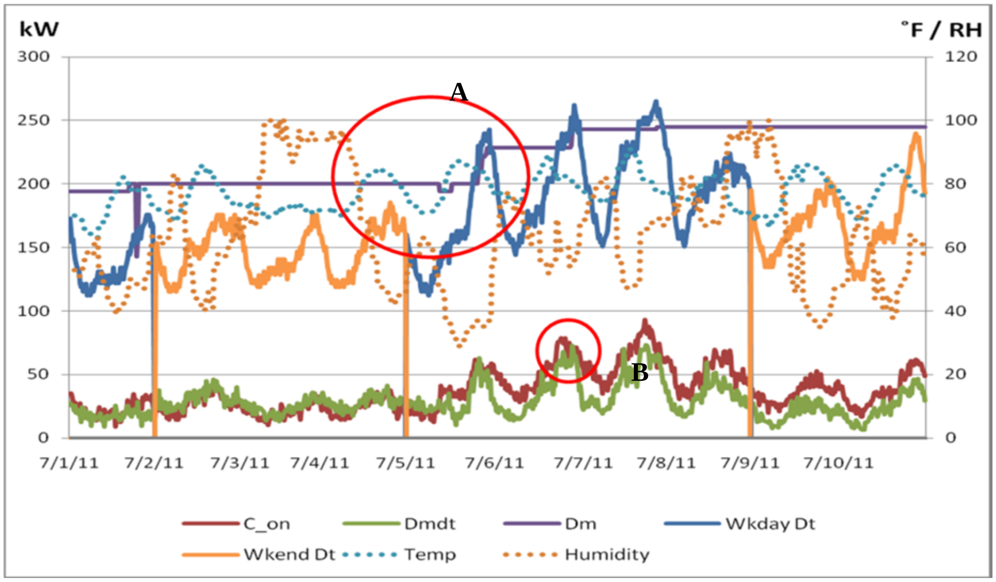

Figure 4-3 Total demand, controlled AC demand, managed demand and outdoor temperature, July 1-July 11

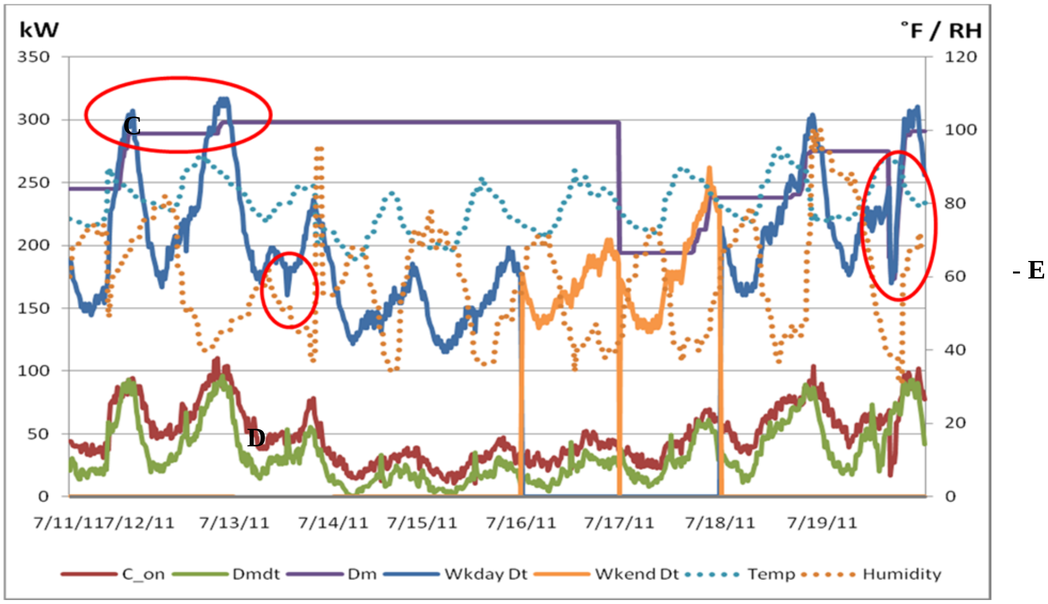

Figure 4-4 Total demand, controlled AC demand, managed demand and outdoor temperature, July 11-July 19

Section 5

DEMAND RESPONSE

During times of peak load on the grid, the New York Independent Systems Operator (NYISO),[11] the organization that manages the electrical supply grid in New York State, may call upon participating customers to reduce their electrical consumption. These periods are known as "curtailment events" and a variety of demand response programs exist to engage and compensate typically larger customers to contribute to this need. In general, customers commit in advance of each cooling season to a specific kW load reduction during the events and are paid a capacity payment regardless of the number of events that actually occur. Events typically last four hours during a weekday afternoon during periods of extreme heat.

Curtailment service providers (CSP) are companies that enroll participants and then commit the aggregated load reduction to the NYISO and/or utility demand response programs. In exchange for managing the process and taking on a portion of the risk in the event that individual participants fail to meet commitments, they retain a portion of the NYISO payments. Jefferson Towers solicited proposals from three curtailment service providers (CSP) offering a share of revenue ranging from 65% to 75% (the CSP would retain the balance). A contract was signed with the CSP that offered the highest share of customer revenue. As is common with CSP agreements, the CSP agreed to absorb any penalties levied by the NYISO in the event that the building failed to meet its commitment due to equipment failure or other reason. The NYISO Special Case Resource (SCR) program baseline procedure requires averaging the building peak demand for the building's top 20 demand hours of the previous summer out of the 40 top system hours specified by the NYISO. The baseline calculation established a baseline of 258 kW for Jefferson Towers.

CURTAILMENT COMMITMENT

Curtailment was to be achieved by affecting three sources of demand within the building: the smart RACs, common area equipment, and voluntary resident curtailment.

Residents of Jefferson Towers who possess one or more of the new fleet-controlled air conditioners were offered enrollment in the building's demand response participation. Enrolled RACs were automatically disabled (compressor only) during curtailment periods. In return, enrolled residents received a share of the compensation from the program ($20 per RAC enrolled in 2011 and $15 per RAC in 2012). Seventy-one units were voluntarily enrolled from 49 apartments in 2011 and 66 units from 42 apartments in 2012.

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[11] The local utility, Consolidated Edison, also offers its own demand response programs.

Additionally, the control system setpoint for the demand management system, operating on the remaining un-enrolled RACs was increased to 75°F to extract additional savings from those units.

A building-wide survey was conducted with the building superintendent to identify common area electrical devices that could be shut during curtailment. The board of directors approved the closure of the laundry room during curtailment, turning off the lobby air conditioning, reducing lighting and other measures. A detailed protocol was developed for building staff to follow during a demand response event. Notices were posted and emails were distributed requesting residents to voluntarily reduce other electrical use during the curtailment period. Table 5-1 lists the devices, rated kW and estimated coincident load during likely curtailment periods (12:00pm to 8:00pm on weekdays) and totals the curtailment potential for 2011. Based on this analysis the building pledged 58 kW into the NYISO program in 2011 and 50 kW in 2012. About 80% of this commitment was due to the smart RAC control system.

Table 5-1 Curtailment commitment calculation for 2011

Equipment	Qty	KW/unit	Total kW	Coincidence	kW Commitment
AC demand management LR	85	1.27	108.0	10%	10.8
AC demand management BR	56	0.85	47.6	10%	4.8
Curtailable LR A/Cs	47	1.27	59.7	40%	23.9
Curtailable BR A/Cs	41	0.85	34.9	40%	13.9
Hallway lighting	38	0.032	1.2	100%	1.2
Lobby lighting	30	0.015	0.5	100%	0.5
Hallway ventilation fans	2	0.29	0.6	100%	0.6
Community room A/Cs	3	1.27	3.8	10%	0.4
Manager's office AC	1	1.3	1.3	10%	0.1
Super's shop AC	1	1.3	1.3	50%	0.7
Lobby central AC	2	3.95	7.9	50%	4.0
Laundry - washers top load	3	0.37	1.1	25%	0.3
Laundry - washers front double	7	0.25	1.8	25%	0.4
Laundry - washers front triple	2	1.5	3.0	25%	0.8
Laundry - dryers	10	0.373	3.7	25%	0.9
Laundry lighting	22	0.02	0.4	50%	0.2
Laundry ventilation fan	1	0.2	0.2	50%	0.1
Laundry AC	1	1.27	1.3	50%	0.6
Voluntary	n/a	n/a	2.0	100%	2.0
Total			**280**		**66.1**
Safety factor					**10%**
Pledge					**59**

CURTAILMENT EVENTS

During the summers of 2011 and 2012 a total of seven demand response events were called. The results of these events are summarized in Table 5-2. The table shows the event date and time, the high temperature for the day, the building kW demand at the start of the event, the average demand during the event, the target demand, and the peak demand for the day and the time that peak occurred. The target demand is equal to the baseline demand for the building calculated according to NYISO procedures, less the demand response commitment that Jefferson Towers pledged to curtail. In the second and third 2011 events, the target was exceeded by 15-20 kW for reasons explained in detail following the table. In 2012, the target was never exceeded except for July 18, when it was exceeded by only 2 kW.

Table 5-2 Summary of Demand Response Events

Date	Time	Daily high OAT (°F)*	Demand at event start (kW)	Average demand during event (kW)	Target demand during event (kW)	Peak demand for the day (kW)	Time of peak demand
July 19, 2011**	4:00pm – 5:00pm	94	247	180	200	315	9:30pm
July 21, 2011	2:00pm – 6:00pm	96	262	220	200	337	10:00pm
July 22, 2011	12:00pm – 4:00pm	103	278	215	200	342	9:15pm
June 20, 2012	2:00pm – 6:00pm	94	172	175	230	298	7:57pm, 9:42pm
June 21, 2012	1:00pm – 5:00pm	93	200	201	230	336	8:32pm, 10:52pm
June 22, 2012	1:00pm – 5:00pm	90	248	204	230	250	5:44pm, 6:54pm, 9:00pm
July 18, 2012	1:00pm – 5:00pm	100	298	232	230	307	12:01pm

* Central Park weather station
** July 19, 2011 was a one-hour test event

On July 19, 2011, a mandatory test of the NYISO demand response system was called from 4:00 pm to 5:00 pm, while the outdoor temperature was in the low 90s. As can be seen in Figure 5-1, which shows the 15-minute demand profile for the day, the system worked properly and the building fulfilled its commitment to maintain demand below 200 Kw for the duration of the test. Approximately 60 controllable RACs were active at the start of the test. Building staff followed the demand response protocol which included turning off various lights and other equipment. Cooling demand reduction was achieved by raising the setpoint on all controllable RACs to 75°F and deactivating the compressor on units scheduled to be curtailed.

Total demand during the event varied from 170 to 189 Kw. Following the test, total building demand rapidly climbed back to about 250 Kw and then continued more slowly ramping up to the daily peak of about 315 Kw at the typical 9:00-10:00 pm timeframe. No resident complaints were recorded. The event had been well-publicized in the building and many residents were at work and not at home.

Figure 5-1 Demand graph screen capture from NYISO test event

On July 21, 2011, a curtailment event was called from 2:00 pm to 6:00 pm. Figure 5-2 shows the 15-minute demand profile for the day. The day's high temperature of 96° F was reached at 2:00pm. The event began as planned: at the onset of the event total demand was curtailed by about 60 Kw. However, shortly thereafter the internet connection failed and commands could not be executed until shortly before 4:00pm when the connection was restored. At the time of this event the demand response mode of the control system was not yet automated and still required an internet connection and intervention by operators. Subsequently, the system was programmed to execute all commands from the local server without the need for a live internet connection.

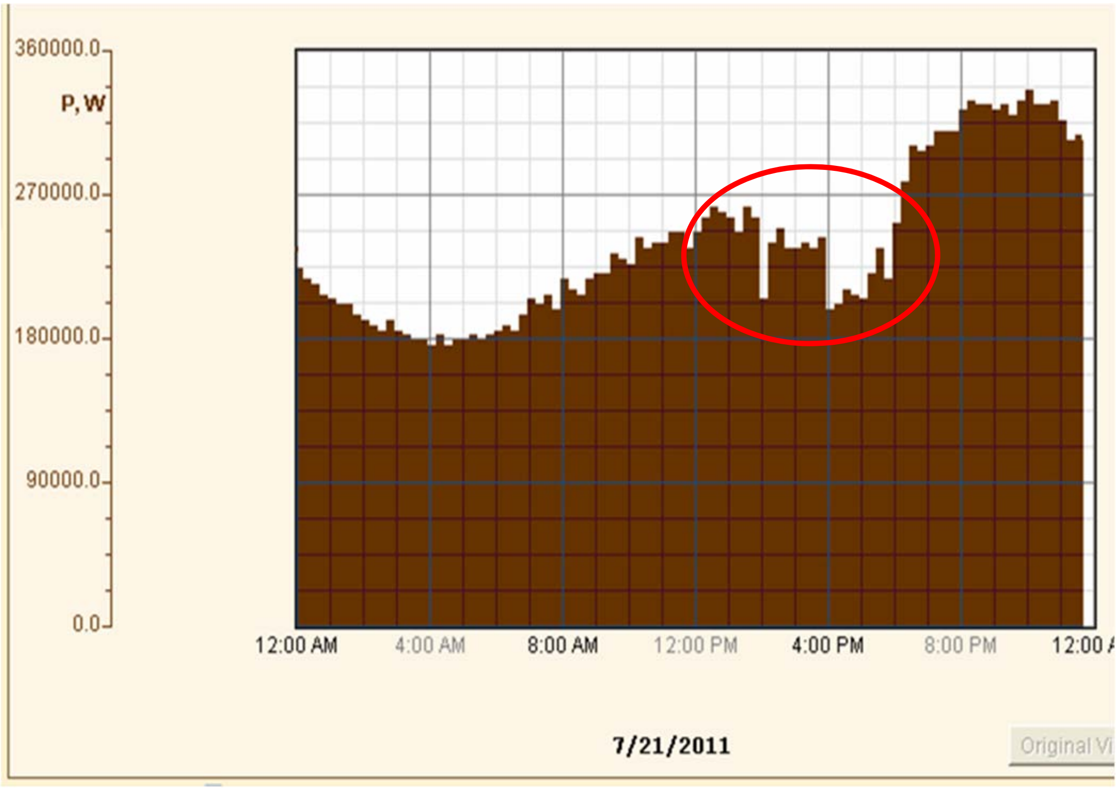


Figure 5-2 Demand graph screen capture from curtailment event on 7/21/2011

On July 22, 2011, another curtailment event was called from 12:00 pm to 4:00 pm. Figure 5-3 shows the 15-minute demand profile for the day. This day was extraordinarily hot, with a high temperature of 103°F at 2:00 pm. At the 12:00 pm onset of the event, total building demand was already 278 kW with approximately 95 of the controllable RACs running.

This event occurred on an extreme temperature day, making it extraordinarily difficult to hold the line on demand while maintaining minimum comfort levels. Initially total demand was curtailed by over 100 kW because more RACs were active than the coincidence factor assumption. After about 90 minutes, a slow-down in wireless communications among the RAC units (especially on the upper floors) caused delays in execution of commands and resulted in a mid-event rise in demand. Aside from this approximately 100-minute period, total building demand was reduced by about 100 Kw.

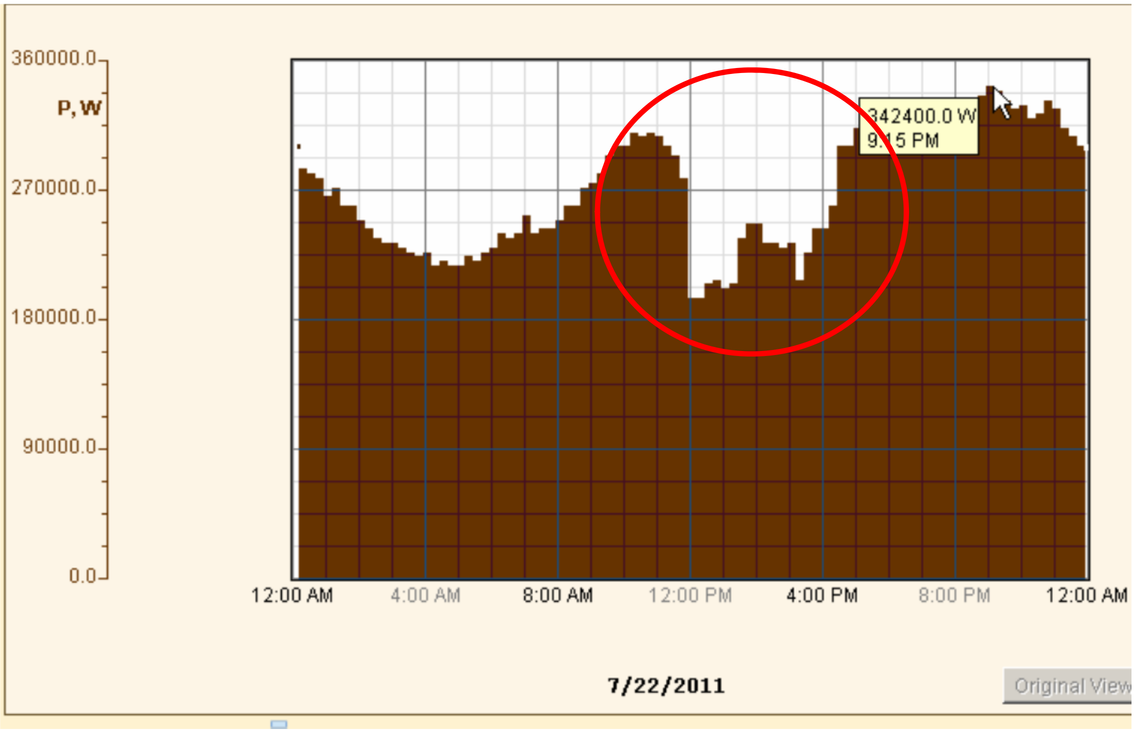


Figure 5-3 Demand graph screen capture from curtailment event on 7/22/2011

Section 6

RESULTS – ENERGY CONSUMPTION

One goal of the project was to quantify utility cost savings attributable to the smart RAC system and thereby determine the value proposition for apartment buildings in New York. For comparison purposes a baseline year for comparison was selected as 2008. The new RACs began installation during the summer of 2010, which eliminated that year as a viable baseline year; and 2009 had an abnormally cool summer with about 24% fewer cooling degree days than 2011. By contrast, 2008 and 2011 had nearly the same number of cooling degree days (1,346 and 1,363 respectively) and 2012 had slightly more (1,472).

As part of the project, 55 RACs were installed where no previous unit existed (i.e. an empty sleeve). Additionally, a new lobby air conditioning system was installed as part of a lobby renovation over the winter of 2010-2011. The additional energy consumption of this cooling equipment was estimated as follows:

- 55 RACs x 0.934 kW (weighted average of 12,000 and 8,000 Btuh units) x 3 hours per day = 154 kWh per day
- 1 lobby AC x 4 kW x 20 hours per day = 80 kWh per day
- 150 days in the 2011 cooling season = 35,000 kWh used by the additional equipment.

The straight weather normalized comparison yields a savings of 5,000 kWh over two years in cooling energy use (about 2%). When adjusted for the additional cooling equipment it results in a savings of 76,000 kWh and 66 kW demand (assuming that kW demand savings is roughly proportional to kWh savings). This translates into a cost savings of $14,400 due solely to the higher efficiency of the new equipment over two years (at the actual rates of $0.115 per kWh supply, $0.057 per kWh delivery and $21.20 per kW demand). The likely additional cooling energy use starting in 2011 resulting from a building-wide increase in fresh air ventilation was not factored into this analysis. Without this change, savings would likely have been higher. The additional kW demand savings as a result of the control system is discussed in the following section.

Table 6-1 Energy (kWh) savings calculations

	2012	2011	2008
Cooling season	May-Sep	May-Sep	June-Sep
kWh used during cooling season	541,600	532,800	444,400
Baseline kWh/day	2,448	2,510	2,392
Days in cooling season	152	150	120
kWh baseline	372,138	376,552	287,095
kWh cooling	169,462	156,248	157,305
Cooling Degree Days	1,454	1,338	1,327
kWh cooling/CDD	116.5	116.8	118.5
Normalized to 2008	154,660	154,964	157,305
Supply Rate	$0.115	$0.115	$0.115
Delivery Rate	$0.058	$0.056	$0.057
Supply & Delivery cost	$26,718	$26,516	$27,046
Cost of operating additional cooling	$6,009	$6,147	n/a
Net cost of operating original (2008) cooling capacity	$20,709	$20,369	$27,046
Savings compared to 2008 due to kWh reduction as a result of improved EER	$6,337	$6,677	$0

Table 6-2 Demand (kW) savings as a result of improved RAC EER calculations

	2012	2011	2008
Cooling season	May-Sep	May-Sep	June-Sep
Average EER all RACs	9.18	9.18	8.77
Cumulative peak kW for cooling season less baseline demand (157kW)	693	701	n/a
kW saved due to approx.. 5% overall RAC efficiency improvement	32.9	33.3	n/a
Demand Rate	$21.20	$21.20	n/a
Demand Savings due to improved EER	$697	$705	n/a

Section 7

RESULTS – DEMAND REDUCTION

The analysis of demand savings due to the control system was conducted in 2012. A series of ON/OFF experiments were conducted over the summer of 2012, with the intent of comparing periods when the control system was operational to when it was inactive. The control system was toggled on/off periodically over the cooling season (May 15 through September 30) in order to capture data for multiple days in each state (ON/OFF) during each of the three periods of the cooling season (Table 7-1). In each period, data for three "hot" days was collected in each mode (ON/OFF) during the early, mid and late summer time frames. "Hot" days are defined as days in which the highest outdoor air temperature is greater than 80°F in May and September and greater than 85°F in June, July and August.

Table 7-1 "Hot" days for each data collection period

Time frame	Dates	On-mode	Off-mode
Early summer	May 15-June 30	7 days	3 days
Mid-summer	July 1-Aug 15	16 days	11 days
Late summer	Aug 16-Sept 30	6 days	0 days

The system settings for the ON and OFF periods are given in Table 7-2. The control algorithm was programmed to maintain a reduced, yet still comfortable level of cooling (maximum return air temperature of 75°F) in order to prevent complaints that may result in a need to reduce setpoints or allow exceptions that could affect data consistency.

Table 7-2 System control settings for ON and OFF periods

System setting	Definition	System ON	System OFF
Dm	Target maximum demand	175	500
SP-on	Set point for RACs permitted to run	68	60
SP-off	Set point for curtailed RACs	75	60
RATmax	Maximum set point allowable	75	60

It should be noted that under intended system operation, the control algorithm may automatically increase Dm over the course of a day and of the utility billing period (i.e. during a heat wave) as necessary to maintain the minimum level of comfort. Because the system only works actively at controlling demand when building demand approaches Dm, during many days the system does not act to depress demand. Therefore for the purposes of this experiment, during periods of System ON, Dm was set artificially low

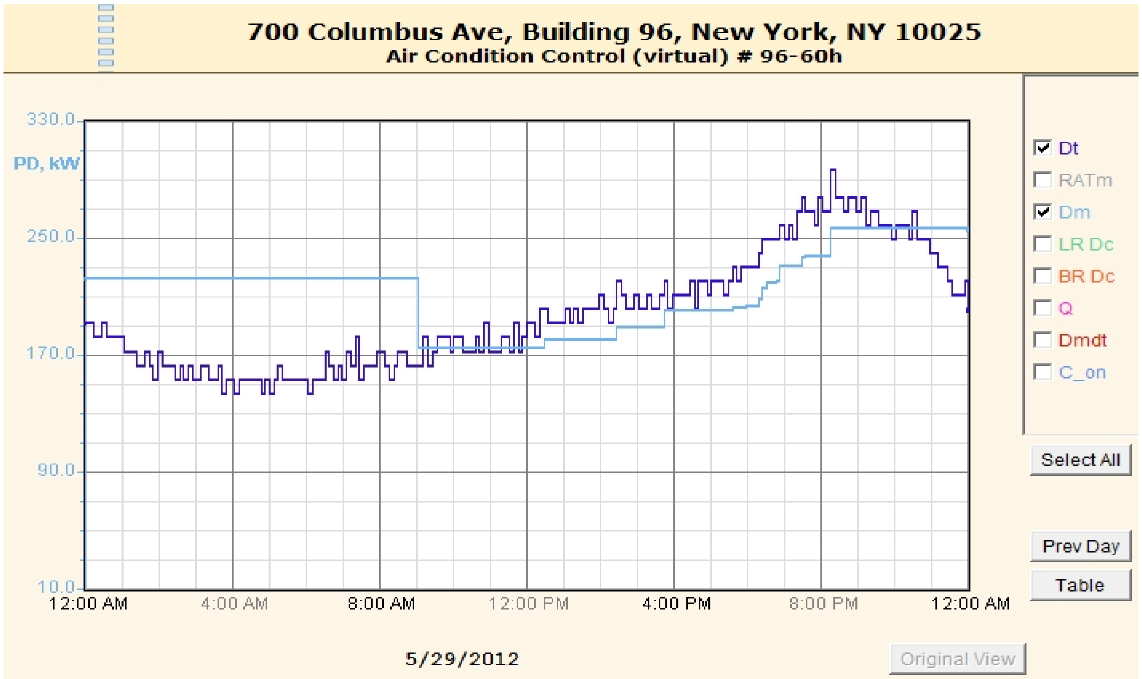
(175 kW) and reset to this value each morning (5:00am), so each day was a new experiment providing usable data. Conversely Dm was set artificially high (500 kW) to deactivate the control system on OFF days. Appendix B lists the ON/OFF days.

DATA COLLECTION

The following data were collected at an interval of 15 minutes or less:

- Total building kW demand
- Outdoor air temperature and relative humidity
- Return air temperature at each RAC unit
- Sum of kW (compressor only) of all active (compressor on) controllable RACs (based on manufacturer listed power requirements, assuming the compressor uses 90% of the unit power with the balance for the fan and controls).
- Status of all controllable RACs (on, off or overridden)

A demand curve for May 29 is shown in Figure 7-1 (the control system logs data every 5-15 minutes). The peak demand on this day occurred approximately between 8:15PM and 8:45PM. It can be seen in the figure, which represents a typical monthly peak demand curve, that the peak occurs rapidly and for a short duration (less than one hour) before demand declines later in the evening.



☑ Dt
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☐ BR Dc
☐ Q
☐ Dmdt
☐ C_on

Figure 7-1 Demand Curve for May 29, 2012

ANALYSIS

The data listed above have been analyzed to answer the following research questions:

- Is the RAC control strategy having the desired effect of reducing total building peak kW demand?
- If there is an effect on kW demand, approximately what is the magnitude of demand reduction?

Table 7-3 shows daily peak demands, time of peak demand, control status, outdoor high air temperature for the day and relative humidity at time of peak demand for six days from May 29 to June 30. Figure 7-2 plots peak demand for all days from May 15 to September 30 as a function of outdoor high air temperature for the day. Figure 7-3 presents the peak demands as a function of the Heat Index[12] at time of peak demand. Heat Index is defined by the U.S. National Oceanic and Atmospheric Administration's National Weather Service as an index that combines air temperature and relative humidity in an attempt to determine the human-perceived equivalent temperature 'how hot it feels.'

An attempt was made to normalize daily peak demand with respect to weather and Heat Index, and compare days when the control system was ON to days when it was OFF. Upon examination of the data in Table 3, a firm conclusion cannot be made as to whether peak demand for a given day is a function of outdoor air temperature, relative humidity or some combination of the two such as the Heat Index. For example, when the control system was OFF on June 20 and June 21, outdoor conditions were very similar, however there was significant difference between the time and magnitude of peak demand. Furthermore, as seen the in figures, the correlation (R-squared) of peak demand with daily high temperature and Heat Index (calculated based on the temperature and humidity at time of peak demand) are 0.84 and 0.87 respectively when the control system was ON and 0.87 and 0.89 respectively when the control system was OFF. This correlation is insufficiently precise to draw quantitative conclusions at the resolution necessary for this analysis (i.e. the average deviation in peak demand at a given outdoor high air temperature or heat index is on the same order of magnitude as the differences in peak demand between Control system ON and Control system OFF modes for days with similar outdoor air temperatures and heat indexes). As discussed below there are numerous factors that affect peak demand. Nevertheless, Figure 7-2 does suggest that at higher heat indexes (above about 78) peak demand is lower with the control system ON. This observation seems less prominent in Figure 7-3 comparing peak demand to peak outdoor temperature.

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[12] The Heat Index, used by the National Weather Service, is a measure of how hot it really feels when relative humidity is factored with the actual air temperature. (http://www.nws.noaa.gov/os/heat/index.shtml#heatindex)

Table 7- 3 Peak demand for six hot days

Day	Control Status	OAT(peak)	RH	Peak Demand (PD)	Time of PD
June 20	OFF	93	53	297.6	9:42 PM
June 21	OFF	93	45	336.0	8:32 PM
June 22	OFF	90	55	249.6	9:00 PM
May 29	ON	88	97	297.6	8:18 PM
June 29	ON	93	47	307.2	9:35 PM
June 30	ON	93	30	249.6	9:35 PM

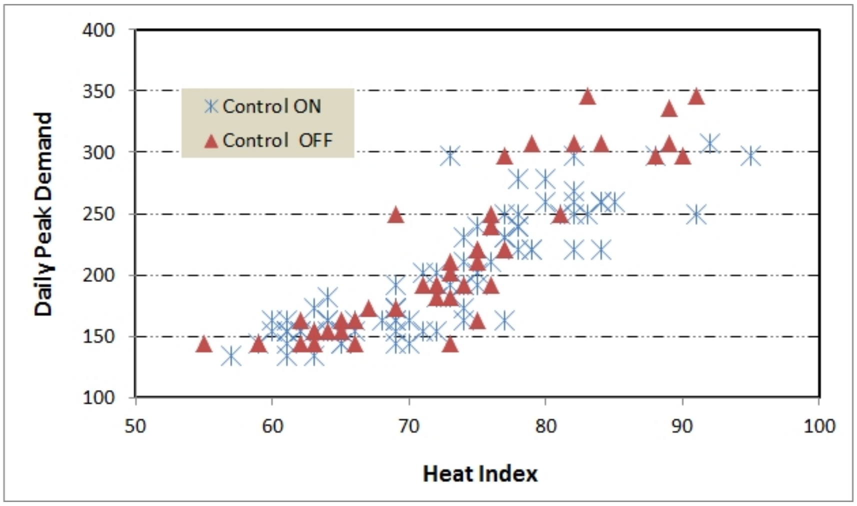

Figure 7-2 Daily peak-demand as a function of heat index - May 15 through September 30

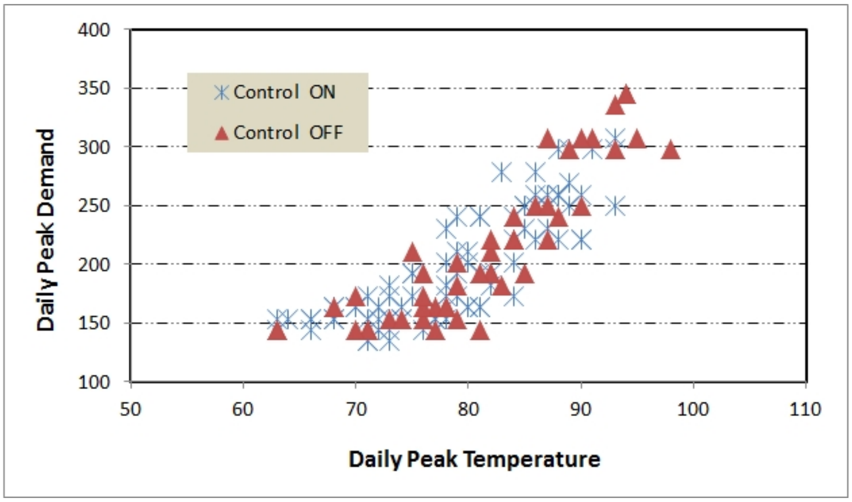

Figure 7-3 Day peak-demand as a function of peak outdoor air temperature - May 15 through Sept. 30

As demonstrated by this analysis, simple weather normalization does not provide a result within acceptable bounds of accuracy. Building peak demand is driven by a complex interaction of peak outdoor temperatures, temperature at time of peak demand, time of peak temperature relative to occupancy, total building occupancy level, relative humidity, precipitation, solar gain, duration of heat waves, day of the week and other factors. It may be possible to develop a more complex model incorporating these other factors; however an alternative method for estimating demand reduction was developed that we believe to be more reliable and accurate. This method is explained and applied below.

As an alternative to weather normalization, a more labor-intensive, but also more reliable and accurate approach to quantifying demand reduction due caused to by the control system was devised. The data on individual RACs provided by the control system were mined for the peak demand hour of the building on the days of highest demand during the period when the control system was ON. When a compressor is listed by the control system as “OFF-OVERRIDEN” it indicates that the control system is preventing that compressor from turning on. The total time each unit is overridden can therefore be summed up and multiplied by each RAC’s power requirements to calculate total avoided demand. However, because under uncontrolled circumstances the compressor may be cycling, it is not a guarantee that the compressor would otherwise be running if not under control. Therefore, it must first be established that in uncontrolled circumstances (i.e. when the control system is OFF) the compressors of all overridden RACs would have been ON (for the vast majority of the time).

In order to establish this, the compressor status for all RACs on a day when the control system was OFF was obtained. On the selected day (July 5), the peak outdoor air temperature and heat index were similar to some of the other days analyzed (Table 7-4). Therefore, if it can be established **that** under uncontrolled circumstances (July 5) (i.e. when the RAC smart control system is OFF on a hot day), the compressors of all RACs were ON during the peak demand hour, it can be concluded that under controlled circumstances, the compressors of all OVERRIDDEN RACs would have been ON during other peak days if the control system was not applied.

Table 7- 4 Heat index, peak outdoor air temperature, outdoor air temperature and RH

Day	Control Status	OAT (peak)	OAT	RH	Peak Demand (PD)	Time of PD	Heat Index
May 29	ON	88	82	97	297.6	8:18 PM	95
June 29	ON	93	89	47	307.2	9:35 PM	92
July 1	ON	93	83	40	297.6	10:23 PM	82
July 5	**OFF**	**94**	**82**	**50**	**345.0**	**9:35 PM**	**83**
Aug 5	ON	89	73	66	297.6	7:57 PM	73
Aug 17	ON	87	73	79	230.4	9:42 PM	74
Sep 1	ON	90	77	68	220.8	8:32 PM	78

The data from July 5 was analyzed as follows. Data from 6:00 PM to 12:00 AM on July 5th was analyzed for all controllable RACs. It was found that 199 RACs were communicating with the control system. Of these RACs, 79 were either ON or were cycling during this period. Fifty-three RACs were found to have cycled at least once during this period of time. Twenty-two RACs were chosen randomly from among the 53 that were cycling during this period of time. These 22 RACs were divided in three groups based on their local set point temperatures (SP), as inferred from the unit's return air temperature: a) SP > 75°F, b) 75°F > SP > 71°F, and c) SP < 71°F. There were five RACs in group 'a', ten RACs in group 'b' and seven in group 'c'. The compressor status of all 22 RACs are presented in Table 7-5.

The RACs in group 'a' are not considered in this analysis because their set-point temperature is higher than the control system set-point temperature and therefore they would always be controlled by the local set point and never overridden (regardless of whether the control system was ON or OFF). The compressors for all but two of the RACs in groups 'b' and 'c' were on for 100% of the time during the peak demand period. The two RACs that did not have their compressors on continuously had them on for 74% and 87% of the time, respectively. This small amount of cycling of these two units results in a total peak demand (for these 22 units) of 1.3% less if they were all running 100% of the time. Therefore, if this example is typical, it can be concluded that the RACs which were OVERRIDDEN on control system ON days, would have been running nearly continuously during the peak demand hour if the control system was not in operation.

Table 7- 5 Compressor status of 22 random RACs during the July 5 peak hour*

Total Number of RACs		22			
No	**Set point T range**	**Apt No**	**Set-point T (°F)**	**Compressor Status**	**Comments**
	SP > 75°F				
1		3D	> 75	**N/A**	
2		9 H Br	> 75	**N/A**	
3		15 C	> 75	**N/A**	
4		20 B	> 75	**N/A**	
5		20 H	> 75	**N/A**	
	75°F > SP > 71°F				
6		2 D	74.5	**ON**	
7		3 G Br	71	**Cycling**	74% time ON
8		4 C	74	**ON**	
9		6 B	72	**ON**	
10		6 B Br	73	**ON**	
11		6 E	72	**ON**	
12		9 F	71	**ON**	
13		9 F Br	74	**Cycling**	87% time ON
14		19 H	74	**ON**	
15		21 G	74	**ON**	
	SP < 71°F				
16		3 E	66	**ON**	
17		3 G	69.5	**ON**	
18		3 J Br	65	**ON**	
19		19 C	70	**ON**	
20		19 K	71	**ON**	
21		19 K Br	66	**ON**	
22		20 E	70	**ON**	

* Control system OFF

Peak Demand Savings Calculation

At Jefferson Towers, there are two types of RACs installed: bedroom units rated by the manufacturer at 0.85 kW, and living room units rated at 1.27 kW. The compressor is assumed to represent 90% of these total unit power ratings. In order to calculate the peak demand reduction due to the control system, the total power of each RAC that is OVERRIDDEN (either partially or fully) during the 30-minute peak demand period when the control system is ON, was calculated. For a given day and time of peak demand, the compressor status of all RACs was obtained for the period 15 minutes before and 15 minutes after the peak demand time. The compressor status for each such RAC was then divided into one-minute time intervals. The average of the power reduction (number of minutes overridden times the RAC compressor power) for these 30 consecutive minutes represents the reduction in peak demand due to the control system.

Table 7-6 shows the compressor status and total number of RACs communicating during the 30-minute peak demand period[13] for six days when the control system was ON. It should be noted that 230 RACs are being controlled in the building (out of a total of approximately 350 RACs installed). It can be seen that fewer than 230 RACs were communicating with the control system, either because they were unplugged or because of imperfections in the wireless mesh network. Definitions of the terms used in Table 7-6 are provided in Table 7-7.

Table 7- 6 Status of controllable RACs during the time of peak demand for six days

Day	ON	Cycling	OFF-Overridden*	Off	OFF	Total RACs communicating	Day of week
May 29	24	27	49	10	82	192	Tuesday
June 29	47	16	33	19	85	200	Friday
July 1	38	19	43	33	66	199	Sunday
August 5	47	12	26	36	81	202	Sunday
August 17	25	12	18	18	124	197	Friday
September 1	18	19	21	17	123	198	Saturday

* Cycling between OFF-Overridden and ON because the local set point was lower than the remote set point

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[13] The peak period definition is consistent with the Consolidated Edison peak demand calculation procedures: "The maximum demand when determined by a demand meter shall be the highest 30 minute integrated demand occurring during the billing period in which such use is made." http://www.coned.com/documents/elecPSC10/GR1-23.pdf Rule 10.4.

Table 7-7 Definitions of RAC status naming convention

Status	Relative to local set point	Relative to remote set point
ON	Calling for cooling	Enabled-because remote set-point NOT satisfied
Cycling	Cycling (ON/Off)	Enabled because remote set point NOT satisfied
OFF-OVERRIDEN	Calling for cooling	Disabled because remote set point satisfied
Off	Satisfied	Enabled because remote set point NOT satisfied
OFF	Satisfied or off by user	Disabled because remote set point satisfied OR off by user

The six days shown in Table 7-6 are the highest peak demand days for each portion of the summer (early, mid and late) from among the days in which the control system was ON. ON/OFF scheduling of the control system in all three periods are presented in Appendix A.

Based on the procedure described above, it was determined that the control system resulted in a total peak demand reduction of from 10 kW to 18 kW at Jefferson Towers. The calculation spreadsheet for May 29 is presented in Appendix B. Based on the results presented above for the data collected on July 5, it is assumed that the RACs which were OVERRIDDEN partially or fully on these six days, would have been running 98.7% of the time during their OVERRIDDEN time if the control system was not in operation. The peak demand savings presented in Table 7-8 were adjusted accordingly.

Table 7-8 also shows which day of the respective heat wave the analyzed day was, counting the number of days since the most recent day on which the high temperature was less than 80°F (May and September) or 85°F (June through August), the outdoor air temperature, the relative humidity, the peak-day demand, and the peak demand savings . Using the results from Table 7-8, peak demand savings as a result of the control system saved Jefferson Towers approximately $1,500 per year in demand charges (Table 7-9).

Table 7-8 Peak demand savings due to control system for six days with control system ON

Day	Day of Heat Wave	Highest OAT of the Day (F)	RH at Time of PD (%)	Time of PD (PM)	Peak Demand (kW)	Peak Demand Savings
May 29*	4th	88	97	8:18	297.6	17.78
June 29	2nd	93	47	9:35	307.2	12.73
July 1	4th	93	40	10:23	297.6	15.68
Aug 5*	4th	89	66	7:57	297.6	13.25
Aug 17	1st	87	79	9:42	230.4	13.12
Sep 1*	3rd	90	68	8:32	220.8	9.68

* Indicates this was the peak demand for the month

Table 7-9 Demand (kW) savings as a result of the control system

	2012	2011
Cooling season	May-Sep	May-Sep
Demand Rate	$21.20	$21.20
kW saved due to control system	71.1	71.5*
Demand Savings due to control system	$1,508	$1,516

* Extrapolated based on 2012 calculations and 2011 demand

Only approximately 66% of the RACs in Jefferson Towers are part of the control system. If 100% of the RACs were part of the controlled system the peak demand savings would have been higher. Table 7-10 shows the extrapolated numbers and the extrapolated savings as a percent of total building peak demand for the six days. Because of the relatively narrow band of percent peak reduction (6.3% to 9.1%) it is taken that the demand savings for these six days is typical of the majority of summer peak demand days. At a rate of $25 per kW demand charge, for the peak days from May through September 2012 the savings would amount to $1,728 for the building, which extrapolates to $2,618 if 100% of the RACs were under control.

Table 7-10 Peak demand savings extrapolated to 100% of RACs

Day	Peak Demand (PD)	Peak Demand Savings	Extrapolated savings	Extrapolated % peak reduction
May 29	297.6 kW	17.78 kW	26.94 kW	9.1%
June 29	307.2 kW	12.73 kW	19.29 kW	6.3%
July 1	297.6 kW	15.68 kW	23.76 kW	8.0%
August 5	297.6 kW	13.25 kW	20.07 kW	6.7%
August 17	230.4 kW	13.12 kW	19.88 kW	8.6%
September 1	220.8 kW	9.68 kW	14.67 kW	6.6%

Based on this analysis of six hot days during the summer of 2012, the RAC control system would have reduced peak demand by approximately 6-9%, if all RACs in Jefferson Towers were part of the control system. Control of both living room and bedroom RACs contributed to the load reduction because the building peak bridges the time when both of these spaces are occupied. This analysis was based on examination of times when the RACs were overridden in combination with an analysis of unit compressor behavior during peak times when the control system was not operating.

This daily peak demand reduction is due solely to the actions of the RAC control system. The sacrifice made by residents to achieve this result was to endure a slightly higher cooling set point (75°F) for brief periods of time during the building's evening peak demand period. Very few (less than five) complaints related to the RAC control system were recorded during the summer of 2012, when the control system was operated 74 of 140 days.[14] This analysis method was determined to be more accurate and reliable than a weather normalization model.

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[14] Because the target maximum demand was set so low (175 kW compared to a typical peak of 275 kW or higher), at least some RACs were curtailed on almost every day the system was active.

Section 8

ECONOMICS

Table 8-1 presents the project implementation costs at Jefferson Towers. It does not include research and development related costs or expenses relating to the administration of the research project. The total cost listed includes the full cost of the retrofitted RAC units. Because Jefferson Towers had a pre-existing communication network as part of its submetering system, there were no additional building-area networking costs. If this system did not exist or were not used, some additional cost likely would be incurred for a base station, wireless repeaters and other equipment.

Table 8-1 Project costs

Item	Quantity	Each	Total
New RAC units	230	$500	$115,000
Wireless control modules installed in RACs	230	$90	$20,700
Installation and disposal	230	$50	$11,500
Smart RAC system set-up and programming (estimated)			$5,000
Total implementation cost (assumes existing communication infrastructure)			$152,200

Table 8-2 summarizes the financial benefits from energy savings, demand reductions and demand response program income and calculates a projected return on investment (ROI) of 21% and an estimated payback of less than five years for the building for this project. If the building were to pay the entire cost of the system without any incentives or subsidies, ROI and payback would be 7% and about 15 years respectively.

Table 8-2 Summary of financial benefits and payback for 2011 through 2012

Item	2011	2012	Avg. per year
Utility costs avoided – consumption (kWh) based on utility bill analysis[15]	$6,539	$6,475	$6,507
Utility costs avoided – demand (kW) attributable to improved RAC EER	$705	$697	$701
Utility costs avoided – demand (kW) attributable to control system	$1,516	$1,508	$1,512
Demand response payments	$1,833	$1,800	$1,817
Total savings/income	$10,593	$10,480	$10,537
ROI / Simple Payback (based on Net cost)	21% / 4.8 years		
ROI / Simple Payback (based on Total cost)	7% / 14.4 years		

Table 8-3 shows the estimated ten-year ownership costs of two scenarios without any subsidies, assuming constant energy costs and demand response benefits. This scenario assumes that residents have a choice of whether to purchase a new smart RAC at their own expense or retain the use of their existing unit. The "Retain old RAC" case includes the cost of establishing a sinking fund for the eventual replacement and installation of a standard new unit when the existing one fails. Over an estimated ten year unit lifespan, costs are similar. Purchasing a new smart RAC becomes more cost advantageous when the existing unit is older and less efficient. One implementation approach would be to install the system infrastructure and some critical number of RACs (replacing only the oldest existing units), and then to continuously add more controllable RACs to the system as older units wear out. The system could be activated once perhaps half of the RACs in the building are controllable.

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[15] Most of this avoided cost is due to the higher efficiency of the new RACs, although a small portion of this energy savings (10-15%) is due to the control system (savings when RAC compressors are overridden for demand management and demand response events).

Table 8-3 Ten year costs per unit

Item	Retain old RAC	Purchase smart RAC
New RAC	$250 (1)	$590 (2)
RAC installation	$25 (3)	$50
Utility costs	$920 (4)	$673 (5)
Demand response payments	N/A	-$80 (6)
Total ten-year cost of ownership	$1,195	$1,233

(1) Assuming a room RAC lasts ten years on average, the existing units are on average half way through their lifespan, and a comparable new standard through-wall RAC costs $500.

(2) Actual per unit costs for retrofit RAC.

(3) Assuming a RAC lasts ten years on average, the existing units are on average half way through their lifespan after which a new unit must be installed, and actual per unit installation costs of $50.

(4) Cooling energy costs for the baseline year divided by 350 RACs

(5) Cooling energy costs for the baseline year (4) multiplied by 0.75 for improved unit EER (based on the average recorded EER of removed units multiplied by a 15% degradation factor for age), less demand charge savings of 2.5% of total bill.

(6) $1833 per year divided over 230 RACs for ten years

Table 8-4 shows the marginal costs and benefits for a smart RAC system for a complete RAC replacement program in a building and assuming the costs and benefits that were estimated for Jefferson Towers. Because in both of the scenarios in this analysis (replacing all RAC with standard units vs. replacing all RACs with smart units and control system), all RACs are replaced, there are no efficiency benefits of the smart RAC system. The financial benefits are limited to demand response income and monthly billing peak reduction due to demand management (extrapolated, assuming 100% of units are controlled and a proportional increase in demand response participation). The ROI is estimated to be approximately 13%.

Table 8-4 Marginal cost of smart RAC system

Item	Total
Incremental cost of smart RAC at $90 per RAC x 350 units	$31,500
Smart RAC system set-up and programming	$5,000
Total incremental costs for smart RAC system	$36,500
Estimated annual demand response income	$2,500
Estimated annual peak demand charge savings due to control system	$2,250
Estimated annual savings/income due to smart RAC system	$4,750
ROI	13%
Simple Payback	7.7 years

Section 9

RESIDENT FEEDBACK

Complaints about cooling and the new RACs were relayed by the superintendent as they came in over the course of the summer. In total only twelve specific complaints were logged over two summers. The complaints were all related to perceptions of poor cooling performance and are summarized below.

- Communications problems preventing unit from promptly returning to lower setpoint: 5
- Retrofit defect leading to low thermostat readings: 2
- Special consideration requiring lower setpoint: 4
- Temporary perception, cured on own: 1

All but two complaints were resolved by implementing a small temperature adjustment to their specific RAC; permitting it to cool to a lower setpoint (the adjustment adds a specified number of degrees F to the temperature sensor reading, effectively fooling the controller that the room is hotter than it really is). The temperature adjustment is added to the RAT, effectively fooling the control system into thinking that the RAT is higher (or lower if the adjustment is a negative number) than it really is. This permits the compressor to run longer (if the adjustment is positive) until the actual RAT equals the RAT sensor measurement less the temperature adjustment.

Additional resident feedback was gathered in 2011 through a survey distributed to all 190 apartments in Jefferson Towers. The survey asked about residents' experience and impressions of the new air conditioners, their thermal comfort during the summer and their involvement in the demand response program. Although only 143 of the 190 apartments received new smart RACs, all apartments were given the survey in order to poll them about the demand response program. A total of 93 apartments responded (49% of all apartments), 81 of which had received smart RACs (57% of smart RAC recipients). Table 9-1 summarizes the survey responses.

Table 9-1 Survey results

Question	Response	
Type of smart RAC in apartment	**% all respondents**	
With living room smart RAC	84%	
With bedroom smart RAC	57%	
None	13%	
Was the purpose of the new RAC system sufficiently explained?	**% all respondents**	
Yes	59%	
Somewhat	26%	
No	8%	
Did not answer	8%	
Did you curtail non-cooling electric usage during demand response events?	**% all respondents**	
Yes	83%	
No	10%	
Did not answer	8%	
Would you like the ability to program your RAC via the internet?	**% all respondents**	
Yes	28%	
No	58%	
Did not answer	14%	
Were the new smart RACs easy to use?	**% respondents with smart RAC**	
1 (hard to use)	5%	
2	1%	
3	22%	
4	20%	
5 (easy to use)	51%	
Would you enroll next year in automatic RAC curtailment (demand response)?	**% respondents with smart RACs**	
Yes	59%	
No	40%	
Were you as cool as you expected to be with the new smart RAC?	**In the living room**	**In the bedroom**
Yes	49%	75%
Sometimes	27%	11%
No	24%	17%

Respondents volunteered the following additional information in the comments section of the survey as shown in Table 9-2.

Table 9-2 Survey comments

Complaint	Number	% of apartments with smart RAC
New RACs noisy	5	6.2%
Electric bill higher than expected	3	3.7%

The results of the survey were presented to the Jefferson Towers board of directors. As a result of the findings, the control system setpoint was lowered in 2012 to improve comfort in subsequent summers. A number of comments were received related to demand response – either enrolled residents whose RACs did not deactivate or non-enrolled residents who's RACs did deactivate. These issues were resolved with software improvements made after July 2011 that automated the curtailment operational mode.

Section 10
CONCLUSIONS

UTILITY DEMAND CHARGE REDUCTION SAVINGS

The control system successfully demonstrated the ability to automatically curtail cooling from a group of individual appliances in a way that minimized the amount of cooling sacrificed while still driving down building demand.

Peak kW demand reduction was analyzed using building daily peak demand data gathered in 2012. Based on an analysis of six hot days during the summer of 2012, the RAC control system would have reduced peak demand by approximately 6-9%, if all RACs in Jefferson Towers were part of the control system. Control of both living room and bedroom RACs contributed to the load reduction because the building peak bridges the time when both of these spaces are occupied. This analysis was based on examination of times when the RACs were overridden in combination with an analysis of unit compressor behavior during peak times when the control system was not operating.

This daily peak demand reduction is due solely to the actions of the RAC control system. The sacrifice made by residents to achieve this result was to experience a slightly higher cooling set point (75°F) for brief periods of time during the building's evening peak demand period. Very few (less than five) complaints related to the RAC control system was recorded during the summer of 2012, when the control system was operated 74 of 140 days.

Greater demand savings may have been possible by increasing the maximum setpoints, perhaps up to 78°F, while targeting more precisely when the controls are activated to limit the duration – i.e. only when demand is expected to peak.

DEMAND RESPONSE

The control system successfully demonstrated the ability to automatically curtail cooling from the controlled RACs in a way that could reduce building demand by a repeatable amount during a demand response event.

System performance was uneven in 2011 primarily for two reasons – 1) poor communications speed with units on upper floors, since corrected with an additional network node midway up the building; and 2) internet connection breakdown, since remediated by programming the curtailment mode of the system to run off the local server. Demand response events in 2012 operated smoothly.

One difficulty with demand response for a residential building in New York City stems from the baseline calculation methods. Using an average of 20 hours to calculate the baseline underestimates the likely load during an event, which typically occurs during the most extreme weather days. And since residential properties peak in the evening – out of synch with the business-dominated afternoon grid peak – the control system has less load to work with (i.e. cooling load is a lower percentage of total load in the afternoon than in the evening). Only about one third of controllable RACs in Jefferson Towers were active at the onset of the demand response events, slightly lower than the 40% estimated for program commitment purposes. Because the outside temperatures (and demand) were significantly higher than that envisioned by the baseline calculation method, demand exceeded the Managed Demand target for a portion of the demand response periods in 2011.

Nevertheless, aside from the brief periods of communications problems, the effective demand reduction was similar to or greater than what had been estimated for commitment, suggesting that the commitment calculation method used by Jefferson Towers was satisfactory. A slightly more conservative commitment in 2012 resulted in successfully meeting the commitment in every event that year, in return for sacrificing some of the incentives.

Finally, as explained below, demand response programs have instituted more stringent requirements in recent years. When the NYISO Installed Capacity (ICAP) program originated, residential buildings could receive incentive payments simply because their normal peak demand fell after the time frame that the ISO was interested in, namely 1:00pm to 7:00pm. These buildings could capture incentive payments without implementing any energy conservation or load management actions. Eventually, the ISO imposed restrictions that required residential buildings to implement load control during the 1:00pm to 7:00pm window. Most residential buildings do not have the ability to reduce load significantly during the daytime hours when their demands are customarily lower. As a result, most residential buildings do not have the ability to receive significant incentives. Smart, automated, space conditioning systems such as at Jefferson Towers enhance this capability, although the monetary benefits are still limited. Additionally, with the small size of potential incentives, many curtailment service providers are hesitant to include mid-size residential buildings in their portfolio because of the moderate kW commitment levels and because of the risk of paying penalties for failure to meet the pledged kW reduction.

EFFICIENCY SAVINGS

Weather normalized cooling energy consumption for the 2011 and 2012 cooling seasons was slightly lower than for the baseline pre-implementation year (2008). When adjusted for an additional 55 RACs and additional lobby cooling system added in 2010/2011, the consumption was about 26% lower – yielding a projected $6,500 in annual savings. This savings is despite the fact that the system was not fully implemented for the entire summer of 2011, and not accounting for the additional cooling energy use likely resulting from a building-wide increase in fresh air ventilation rates in early 2011.

COMFORT

Comfort was evaluated through tracking of complaints and via an occupant survey. The survey revealed a desire by residents for more cooling, however the desire did not reach the point of generating significant complaints.

COMMERCIALIZATION

A unique feature of this project was the integration of electrical submetering with both heating and cooling control. Cooling control was implemented to reduce building peak electrical demand and facilitate the building's demand response participation during the cooling season while maintaining resident comfort. Jefferson Towers had already integrated the heating system controller with the wirelessly communicating submeter system in order to optimize winter steam consumption. Cooling control was achieved by controlling the air conditioners in such a manner as to minimize resident complaints, prevent tampering with the system and obtain the desired demand management and demand response capability. To achieve this objective required controlling the RAC units with a device internal to the RAC chassis, thereby permitting separate control of the compressor and the re-circulating fan and a time-delay on compressor re-start so as to not nullify the RAC manufacturer's warranty.

The system at Jefferson Towers does not depend on installation into a plugged-in wall device that could be circumvented by plugging the RAC into a different electrical outlet. Nor does it depend on the residents' access to a computer or Internet or installing software on their home computer. An additional benefit of the separate control of the compressor and re-circulating fan is that by permitting fan operation after disengaging the compressor, the comfort level in the apartment is better maintained and the psychological impact on the resident is improved because he/or she may not be aware their RAC is being controlled.

This technology development and demonstration is unique in the New York multifamily building market segment. With some refinement, the control strategy could be market ready and the hardware used in the Jefferson Towers project is proven to work. They are not yet in commercial use in the New York multifamily market segment. The project provides a needed case study, local example and data to verify technical and financial viability of a fleet-controlled room air conditioner system. Such demonstrations are needed to pique the interest of manufacturers, utilities, government programs and buildings in these technologies.

However, the challenge in obtaining RACs incorporating custom modifications such as needed for this project should not be underestimated. The major RAC manufacturers find it difficult to justify modifying products for an unproven application unless many thousands of units are required. Furthermore, technical support and warranty service on specialty units would likely be poor due to the local service organizations being unfamiliar with the unusual product.

There are small specialty manufacturers with the capability to make custom smart RACs; however their cost for limited production runs is prohibitive. Demonstrations such as this project can help prove to the large manufacturers that integrating wireless control capability for demand response and load management is a worthwhile endeavor. As appliances begin incorporating internet connectivity and open wireless standards become more prevalent, this problem may be resolved.

For master-metered buildings, tying the room air conditioner (RAC) control system into a pre-existing wireless submetering system makes sense. Whether or not such a system exists, a method is needed to provide a robust wireless network and connect it to a central control point. Ideally, controllable-ready (or demand response ready) RACs would be available off-the-shelf from major manufacturers that could easily plug into a self-organizing and self-healing wireless mesh network. The system would require one or more access points, or media-independent nodes linked to a single access point. A shadow master kW demand meter is also needed. One cost-effective implementation approach may be to install the system infrastructure and some critical number of RACs (replacing only the oldest existing units), and then to continuously add more controllable RACs to the system as older units wear out. The system could be activated once a critical mass of the RACs in the building are controllable.

Communications standards such as USNAP or ZigBee[1] exist as possible alternatives to the communications system employed at Jefferson Towers. However they may be less suitable for large multifamily installations due to limitations on the number of devices that can connect to a single wireless node and because of network security concerns. The Intech 21 system used at Jefferson Towers does not share these issues.

FURTHER RESEARCH

A number of additional research questions were identified during the course of this work that could be addressed in the future at Jefferson Towers or other research sites. While a number of different setpoints were used at Jefferson Towers in order to find a balance between energy/demand savings and comfort, a systematic optimization of setpoints and their impact on comfort and kW/kWh savings could be conducted. Other control algorithms could be tested (such as cycling instead of demand rationing) and their impact on kW reduction and comfort evaluated. While the control system at Jefferson Towers is highly flexible, it may be possible that a more sophisticated, intelligent control system that learns from operational, temperature or even resident input can substantially enhance results.

Finally, a demonstration and evaluation of an open networking solution with off-the-shelf RACs or heat pumps could be conducted to evaluate the costs and effectiveness of a similar large multifamily application.

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APPENDIX A – ON/OFF Scheduling of the Control System

The following table lists each day of the 2012 cooling season, the control system status for the day (ON or OFF) and other relevant factors such as high temperature, heat index and peak demand. The days shown in bold are the analysis days.

Day-Month	Highest Day Temperature	Temperature at the time of PD	RH at the time of PD	Heat Index at the time of PD	Time of PD	Peak Demand (PD)
	F	F	%	F		kW
Control ON						
15-May	64	62	100%	63	8:46 PM	153.6
16-May	78	71	68%	71	9:14 PM	153.6
17-May	71	63	46%	61	9:14 PM	153.6
18-May	71	59	48%	57	9:00 PM	134.4
19-May	77	62	58%	61	10:10 PM	153.6
20-May	77	67	40%	65	9:07 PM	144.0
21-May	63	61	97%	61	9:21 PM	153.6
22-May	70	66	84%	66	9:42 PM	163.2
23-May	74	65	90%	65	9:28 PM	153.6
24-May	66	63	100%	64	8:39 PM	153.6
25-May	73	68	96%	69	8:32 PM	144.0
26-May	84	73	90%	74	10:45 PM	172.8
27-May	81	73	76%	74	7:36 PM	163.2
28-May	89	77	69%	78	9:35 PM	249.6
29-May	**88**	**82**	**97%**	**95**	**8:18 PM**	**297.6**
Control OFF						
30-May	75	73	67%	73	9:35 PM	211.2
31-May	79	73	40%	72	9:28 PM	182.4
1-Jun	73	63	82%	63	9:35 PM	153.6
2-Jun	74	64	54%	63	11:20 PM	153.6
3-Jun	76	65	70%	64	8:11 PM	153.6
4-Jun	63	56	75%	55	8:53 PM	144.0
5-Jun	63	60	77%	59	9:35 PM	144.0
6-Jun	71	59	93%	59	9:00 PM	144.0
7-Jun	77	67	63%	66	10:10 PM	144.0
8-Jun	81	74	43%	73	9:07 PM	144.0
9-Jun	78	75	55%	75	9:07 PM	163.2
10-Jun	82	71	74%	71	9:35 PM	192.0
11-Jun	77	66	70%	66	9:21 PM	163.2
12-Jun	70	66	96%	67	9:14 PM	172.8

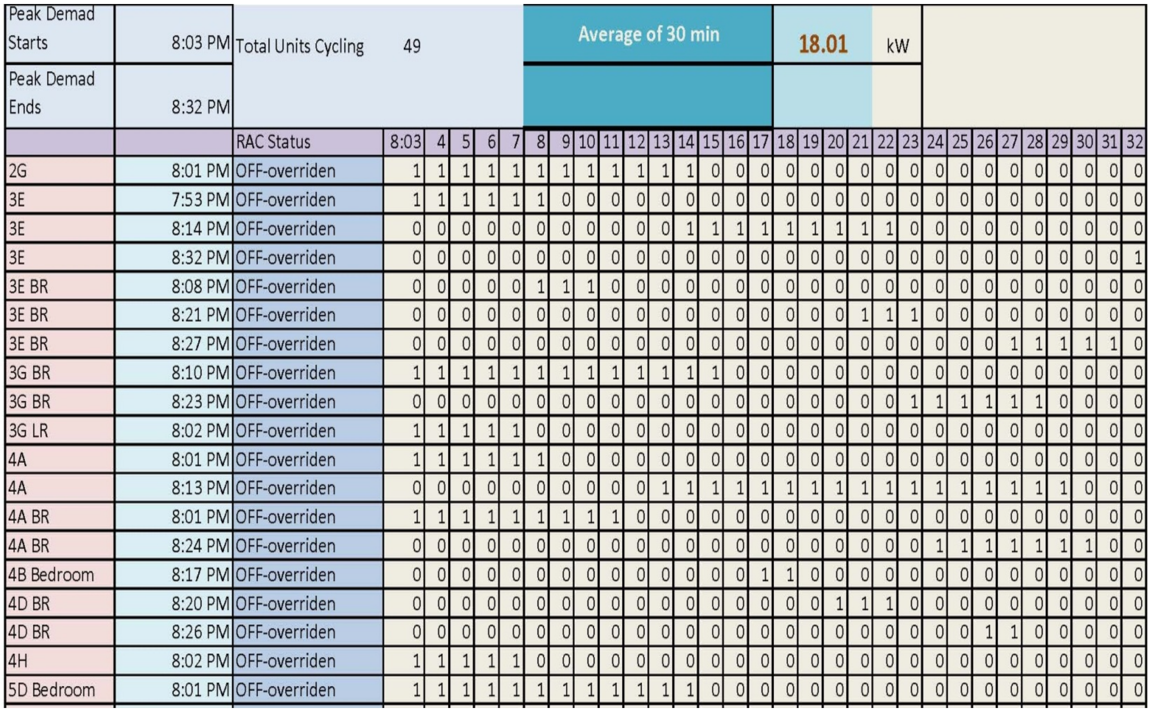
Day-Month	Highest Day Temperature	Temperature at the time of PD	RH at the time of PD	Heat Index at the time of PD	Time of PD	Peak Demand (PD)
	F	F	%	F		kW
13-Jun	68	65	90%	65	10:31 PM	163.2
14-Jun	76	66	78%	66	8:53 PM	163.2
15-Jun	78	63	68%	62	11:20 PM	163.2
16-Jun	79	65	76%	65	9:00 PM	153.6
17-Jun	71	63	75%	63	9:49 PM	144.0
18-Jun	70	62	77%	62	9:35 PM	144.0
19-Jun	76	69	82%	69	9:35 PM	172.8
20-Jun	93	87	53%	90	9:42 PM	297.6
21-Jun	93	88	45%	89	8:32 PM	336.0
22-Jun	90	70	55%	69	9:00 PM	249.6
23-Jun	82	77	40%	76	9:35 PM	192.0
24-Jun	82	75	60%	75	8:46 PM	211.2
Control ON						
25-Jun	73	64	77%	64	10:31 PM	182.4
26-Jun	71	62	67%	61	1:24 AM	134.4
27-Jun	81	78	33%	77	9:14 PM	163.2
28-Jun	88	82	43%	82	9:56 PM	220.8
29-Jun	**93**	**89**	**47%**	**92**	**9:35 PM**	**307.2**
30-Jun	93	83	30%	81	9:35 PM	249.6
1-Jul	**93**	**83**	**40%**	**82**	**10:23 PM**	**297.6**
2-Jul	88	81	36%	80	9:35 PM	259.2
3-Jul	88	80	60%	82	10:03 PM	259.2
4-Jul	91	86	51%	88	11:13 PM	297.6
Control OFF						
5-Jul	94	82	50%	83	9:35 PM	345.6
6-Jul	91	82	60%	84	10:24 PM	307.2
7-Jul	95	87	50%	89	7:36 PM	307.2
8-Jul	90	80	64%	82	9:07 PM	307.2
9-Jul	84	76	54%	76	9:28 PM	240.0
10-Jul	86	76	60%	76	10:24 PM	249.6
11-Jul	84	75	60%	75	9:14 PM	220.8
12-Jul	88	76	55%	76	8:32 PM	240.0
13-Jul	87	79	64%	81	9:28 PM	249.6
14-Jul	82	76	71%	77	11:34 PM	220.8
15-Jul	87	77	94%	79	8:53 PM	307.2
16-Jul	89	86	49%	88	8:46 PM	297.6
17-Jul	94	89	45%	91	8:46 PM	345.6
18-Jul	98	75	97%	77	9:42 PM	297.6

Day-Month	Highest Day Temperature	Temperature at the time of PD	RH at the time of PD	Heat Index at the time of PD	Time of PD	Peak Demand (PD)
	F	F	%	F		kW
Control ON						
19-Jul	75	74	74%	74	8:11 PM	192.0
20-Jul	68	63	96%	64	7:49 AM	163.2
21-Jul	77	69	70%	69	10:52 PM	163.2
22-Jul	82	72	71%	72	9:56 PM	182.4
23-Jul	86	83	80%	91	8:39 PM	249.6
24-Jul	90	84	47%	85	8:25 PM	259.2
25-Jul	84	79	42%	79	8:24 PM	220.8
26-Jul	87	80	80%	84	7:36 PM	259.2
27-Jul	86	82	58%	84	9:49 PM	259.2
28-Jul	78	70	93%	71	9:00 PM	201.6
29-Jul	79	73	79%	74	9:56 PM	211.2
30-Jul	79	74	71%	74	6:54 PM	192.0
31-Jul	80	71	81%	72	9:49 PM	201.6
1-Aug	75	72	94%	73	9:14 PM	192.0
2-Aug	87	79	74%	82	10:52 PM	249.6
3-Aug	88	81	65%	84	8:39 PM	259.2
4-Aug	89	79	83%	82	9:28 PM	268.8
5-Aug	**89**	**73**	**66%**	**73**	**7:57 PM**	**297.6**
6-Aug	85	77	48%	77	9:14 PM	249.6
7-Aug	81	75	70%	75	9:35 PM	240.0
8-Aug	83	77	83%	78	8:46 PM	278.4
9-Aug	86	78	82%	80	9:49 PM	278.4
10-Aug	79	77	82%	78	8:11 PM	240.0
11-Aug	85	80	69%	83	7:36 PM	249.6
12-Aug	85	77	57%	77	9:56 PM	230.4
13-Aug	84	78	48%	78	8:53 PM	240.0
14-Aug	78	76	82%	77	10:59 PM	230.4
15-Aug	81	68	94%	69	8:11 PM	192.0
16-Aug	84	75	54%	75	10:31 PM	201.6
17-Aug	**87**	**73**	**79%**	**74**	**9:42 PM**	**230.4**
18-Aug	78	70	44%	69	10:38 PM	172.8
19-Aug	73	70	53%	69	9:28 PM	172.8
Control OFF						
20-Aug	76	72	64%	72	8:18 PM	192.0
21-Aug	81	74	62%	74	8:53 PM	192.0
22-Aug	79	73	66%	73	10:38 PM	201.6
23-Aug	84	75	66%	75	10:52 PM	220.8

Day-Month	Highest Day Temperature	Temperature at the time of PD	RH at the time of PD	Heat Index at the time of PD	Time of PD	Peak Demand (PD)
	F	F	%	F		kW
24-Aug	87	77	56%	77	9:14 PM	220.8
25-Aug	85	72	58%	72	11:26 AM	192.0
26-Aug	83	73	73%	73	8:18 PM	182.4
Control ON						
27-Aug	81	76	91%	78	9:21 PM	240.0
28-Aug	86	79	50%	79	9:21 PM	220.8
29-Aug	78	74	41%	73	8:46 PM	182.4
30-Aug	82	76	43%	75	9:14 PM	192.0
31-Aug	90	84	43%	84	8:25 PM	220.8
1-Sep	**90**	**77**	**68%**	**78**	**8:32 PM**	**220.8**
2-Sep	80	75	82%	76	8:46 PM	211.2
10-Sep	71	65	41%	63	8:25 PM	172.8
11-Sep	72	66	43%	64	9:14 PM	163.2
12-Sep	80	69	57%	68	9:07 PM	163.2
13-Sep	79	69	68%	69	8:39 PM	172.8
14-Sep	80	70	71%	70	9:14 PM	163.2
15-Sep	72	66	47%	65	9:21 PM	144.0
16-Sep	73	70	40%	69	7:32 PM	153.6
17-Sep	77	67	55%	66	9:07 PM	153.6
18-Sep	75	68	100%	69	7:50 PM	172.8
19-Sep	70	62	50%	60	9:42 PM	163.2
20-Sep	68	63	72%	62	9:14 PM	153.6
21-Sep	73	64	70%	63	7:57 PM	134.4
22-Sep	74	71	84%	72	7:36 PM	153.6
23-Sep	68	63	44%	61	7:36 PM	163.2
24-Sep	66	61	44%	59	7:36 PM	144.0
25-Sep	72	66	61%	65	8:04 PM	153.6
26-Sep	76	70	76%	70	7:57 PM	144.0
27-Sep	74	69	68%	69	9:14 PM	163.2
28-Sep	68	62	93%	62	9:56 PM	153.6
29-Sep	63	62	72%	61	7:22 PM	144.0
30-Sep	66	61	60%	60	9:21 PM	153.6

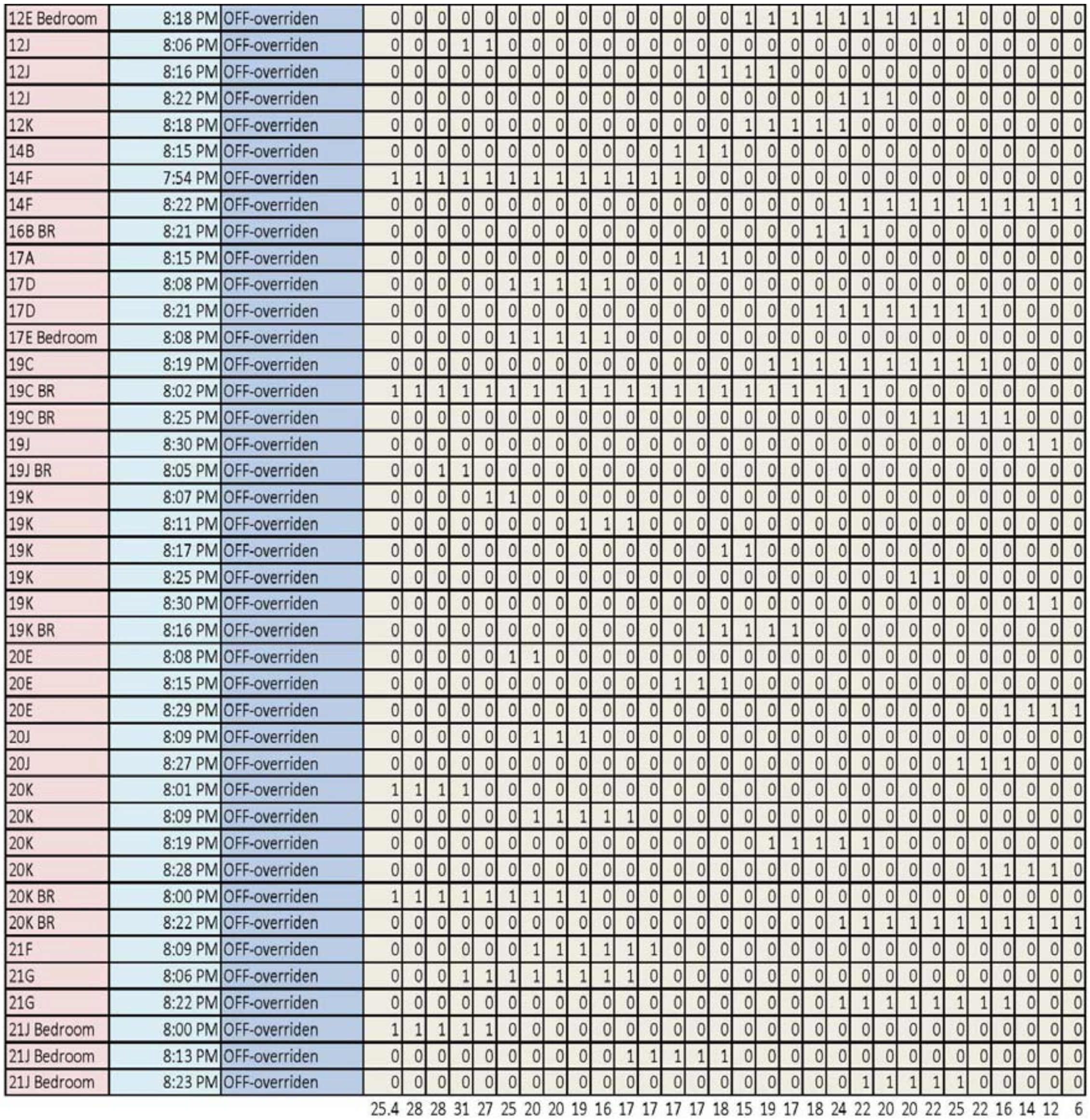
APPENDIX B – Peak Demand Reduction Calculations for May 29, 2012

The following table illustrates the spreadsheet analysis used to calculate peak demand reduction for May 29, 2012. For this day, the 30-minute peak period begins at 8:03PM. Each row in the table represents an RAC at a given time interval. The minutes from 8:03 to 8:32 are listed in the columns. The number “1” in a cell indicates that the RAC was overridden for that minute. Where an RAC is listed multiple times, it is because it had alternating periods of running and being overridden. For example, the RAC in apartment 3E was overridden from 8:03 to 8:08, allowed to run from 8:09 to 8:13, overridden again from 8:14 to 8:22, allowed to run from 8:22 to 8:31, and then overridden again starting at 8:32. Each “1” in the table is multiplied by that unit’s compressor power requirement and added up. The last row in the table totals up the number of overridden compressor-minutes for each minute of the 30-minute peak period.



Peak Demad Starts	8:03 PM	Total Units Cycling	49				Average of 30 min										18.01		kW													
Peak Demad Ends	8:32 PM																															
		RAC Status	8:03	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
2G	8:01 PM	OFF-overriden	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3E	7:53 PM	OFF-overriden	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3E	8:14 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
3E	8:32 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
3E BR	8:08 PM	OFF-overriden	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3E BR	8:21 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
3E BR	8:27 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0
3G BR	8:10 PM	OFF-overriden	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3G BR	8:23 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0
3G LR	8:02 PM	OFF-overriden	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4A	8:01 PM	OFF-overriden	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4A	8:13 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
4A BR	8:01 PM	OFF-overriden	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4A BR	8:24 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0
4B Bedroom	8:17 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4D BR	8:20 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
4D BR	8:26 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
4H	8:02 PM	OFF-overriden	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5D Bedroom	8:01 PM	OFF-overriden	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5D Bedroom	8:22 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0
5H	8:14 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5H	8:19 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
5H	8:30 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
6B	8:01 PM	OFF-overriden	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6C BR	8:16 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6C BR	8:29 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
6D Bedroom	8:01 PM	OFF-overriden	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6D Bedroom	8:16 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
7C	8:01 PM	OFF-overriden	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7C	8:11 PM	OFF-overriden	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7C	8:19 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0
7C	8:29 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
7G Bedroom	8:03 PM	OFF-overriden	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7G Bedroom	8:16 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
7G Bedroom	8:29 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
7K	8:03 PM	OFF-overriden	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8C	8:03 PM	OFF-overriden	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8C	8:08 PM	OFF-overriden	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8C	8:13 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8C	8:19 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
8C	8:27 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
8H BR	8:14 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
8H BR	8:24 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0
8K	8:30 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
9F	8:10 PM	OFF-overriden	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9F	8:26 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
9F Bedroom	8:04 PM	OFF-overriden	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9H BR	8:27 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
10J	8:04 PM	OFF-overriden	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10J	8:16 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
10J	8:22 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
11A	8:07 PM	OFF-overriden	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11A	8:21 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
11E	8:24 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0
11E BR	8:00 PM	OFF-overriden	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12A Bedroom	8:01 PM	OFF-overriden	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12C	7:54 PM	OFF-overriden	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12C	8:15 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
12C BR	8:01 PM	OFF-overriden	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12C BR	8:22 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0
12E Bedroom	8:00 PM	OFF-overriden	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0



12E Bedroom	8:18 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
12J	8:06 PM	OFF-overriden	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12J	8:16 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
12J	8:22 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
12K	8:18 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
14B	8:15 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14F	7:54 PM	OFF-overriden	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14F	8:22 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
16B BR	8:21 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
17A	8:15 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17D	8:08 PM	OFF-overriden	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17D	8:21 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
17E Bedroom	8:08 PM	OFF-overriden	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19C	8:19 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0
19C BR	8:02 PM	OFF-overriden	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
19C BR	8:25 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0
19J	8:30 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
19J BR	8:05 PM	OFF-overriden	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19K	8:07 PM	OFF-overriden	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19K	8:11 PM	OFF-overriden	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19K	8:17 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19K	8:25 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
19K	8:30 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
19K BR	8:16 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
20E	8:08 PM	OFF-overriden	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20E	8:15 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20E	8:29 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
20J	8:09 PM	OFF-overriden	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20J	8:27 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
20K	8:01 PM	OFF-overriden	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20K	8:09 PM	OFF-overriden	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20K	8:19 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0
20K	8:28 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0
20K BR	8:00 PM	OFF-overriden	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20K BR	8:22 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
21F	8:09 PM	OFF-overriden	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21G	8:06 PM	OFF-overriden	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21G	8:22 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0
21J Bedroom	8:00 PM	OFF-overriden	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21J Bedroom	8:13 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21J Bedroom	8:23 PM	OFF-overriden	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0
			25.4	28	28	31	27	25	20	20	19	16	17	17	17	17	18	15	19	17	18	24	22	20	20	22	25	22	16	14	12	6